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Assessment of Ecosystem Goods and Services provided by the Coastal Zone System Limfjord

Anita Wiethüchter

SPICOSA
Science **P**olicy **I**nterface for **Co**astal **S**ystems **A**ssessment
Study Site Limfjorden, Denmark

Project N° : 036992

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Contents

English Summary

A coastal system such as the Limfjord provides a range of goods and services. This includes fish and mussels, sand or other raw materials, shipping transport, experience of nature, beaches and reduction of atmospheric CO_2 content. Several of these goods and services are freely accessible and therefore not valued economically as such. The consequence is often that these may be overseen, during decision-making by politicians or authorities on spatial planning. An important aspect of sustainable coastal management is, therefore, knowing which goods and services a particular system provides.

This report identifies and defines ecosystem goods and services provided by the coastal zone (CZ) ecosystem Limfjord in North Jutland, Denmark. The aim of this research was to identify, list and characterize the ecosystem goods and services (EGS), the basis for economic valuation.

The results of this study show that there are significant data gaps especially concerning services that are characterized in being non-extractive and having non-use values. Thus this work supports the idea that an already established framework of goods and services needs to be applied among Study sites. First to enable comparison between studies and second, given the short time-frame, to make benefit transfer of values possible.

This study was part of the work performed for the Limfjord Study Site, WP7, Node 3 within the Integrated Project funded by the European Community under the 6th Framework Programme, Priority 1.1.6.3, Global Change and Ecosystems. Information on this project can be obtained at the website www.spicosa.org. The work was carried out as a 3-month study under the joint supervision of Ass. Prof. Eva Roth, Head of Department, University of Southern Denmark and Dr. Josianne G. Støttrup, DTU Aqua.

Dansk sammenfatning

Et kystzone-økosystem som Limfjorden forsyner sine omgivelser med en lang række ressoucer og tjenesteydelser (*Ecosystem Goods* and *Services*). Det kan f.eks. være fisk og muslinger, sand og andre råstoffer, transportveje til skibe, naturoplevelser, badestrande og reduktion af atmosfærens CO_2-indhold. Mange af disse ressourcer og tjenesteydelser er frit tilgængelige og bliver derfor ikke værdisat i økonomisk forstand. Konsekvensen er ofte, at de overses, når f.eks. politikere og myndigheder skal beslutte, hvordan et område skal udnyttes. Et vigtigt element i bæredygtig kystzone-forvaltning er derfor at vide, hvilke ressourcer og tjenesteydelser et konkret økosystem bidrager med.

Rapporten identificerer og beskriver Limfjordens økosystemressourcer og -tjenesteydelser og peger på, hvordan man kan måle og værdisætte dem. Rapporten viser, at der i høj grad mangler data, især for de ydelser, som ikke udvindes direkte, og som ikke har nogen umiddelbar brugsværdi, f.eks. hensynet til kommende generationers adgang til økosystemet. Rapporten støtter dermed antagelsen om, at der bør implementeres en fælles ramme for forståelsen af

økosystemressourcer og -tjenesteydelser, så man kan sammenligne forskellige studier og overføre resultater fra ét område til et andet.

Rapporten indgår i Limfjord Study Site, som er en del af SPICOSA-projektet, der er finansieret af EU (www.spicosa.org). Arbejdet blev udført som et 3-måneders studie under fællesvejledning af assisterende professor og afdelingsleder Eva Roth, Syddansk Universitet og seniorforsker Josianne G. Støttrup, DTU Aqua.

1. INTRODUCTION

Ecosystems provide people with a flow of Ecosystem goods and services (EGS) which directly or indirectly contribute to our well being. The value of these ecosystem services, and the natural assets that provide them, is often overlooked in decisions about resource use, not because they are not important, but because they are freely available rather than bought and sold through markets (Vaze *et al*. 2006).

Increasing consumption per person, multiplied by a growing human population, are the root causes of the increasing demand for ecosystem services thus causing changes in ecosystems (MEA 2003). Because many ecosystem services are not traded in markets, markets fail to provide appropriate signals that might otherwise contribute to the efficient allocation and sustainable use of the services. Even if people are aware of the services provided by an ecosystem, they are neither compensated for providing these services nor penalized for reducing them (MEA 2005).

Defining ecosystem processes and resources in terms of EGS translates the complexity of marine biodiversity into a series of functions, which can be more readily understood, for example by policy-makers and non-scientists (Beaumont *et al*. 2007). Furthermore, utilising an EGS-framework reduces the likelihood that environmental managers will overlook certain goods and services when making a decision (Beaumont *et al*. 2007).
Furthermore, the EGS-framework enables an integration of the three pillars of society – environment, economic and social services, into a sustainable coastal zone (CZ) management.

This interdisciplinary approach is of particular importance because of the services area known to be extremely important and to be highly threatened, very little is known about marginal values (the net benefit or cost associated with protecting or destroying the next unit of an ecosystem) or about the nonlinearities in ecosystem responses to human impact. Often this information is not acquired until after it is too late to reverse the harm done (Daily 2000).

The objective of this 3-months study is to identify, list and characterize the EGS provided by the Limfjord, based on opinions of experts/ stakeholders.

The gathered information will provide the basis for quantification and valuation of the identified EGS to help public sector decision making. Economic valuation is of importance because it translates physical terms into economic terms (money), which can be more readily understood by decision-makers and the general public.

The key question in environmental economics is how to value the series of benefits that EGS give to society. The fundamental aim is not to put a ‘‘$ price tag’’ on the environment, or its component parts, but to express the effect of a marginal change in ecosystem services provision in terms of a rate of trade off against other things people value (Randall 2002; Hanley and Shogren, 2002). It is important to note that what is, therefore, being valued is not biodiversity per se, but rather interdependent elements of ecological services (Turner *et al*. 2003). Besides the “use values" of EGS, many goods and services are valued for reasons not related to direct/indirect use and have a non-use value. The aggregation of use and non-use values provided by an ecosystem appears in environmental economics as the total economic value (TEV). The TEV does not reflect the "total system value" because the continued functioning of a healthy ecosystem is more than the sum of its individual functions/ components (Turner *et al*. 2003). The TEV is rather used as a tool to compare and rank EGS in their importance for e.g. conservation according to their benefits to society. "*Estimating even a minimum value for a subset of the services that functioning ecosystems provide may help establish a higher priority for their conservation*" (Losey and Vaughan 2006). The different economic values and economic valuation techniques available will be shortly explained and set in context with the EGS identified.

The discussion will focus on the viability of the EGS approach in the CZ Limfjord.

2. STUDY SITE

The examined Coastal Zone (CZ) system is the Limfjord situated in North Jutland (Fig.2.1).

With a surface area of 1500 km^2 and about 1000 km of coastline, the Limfjord is the largest fjord in Denmark. It has a western inlet to the North Sea and a narrow channel leading to the Kattegat. The catchment area of the fjord is 7528 km^2 of which 62% of the area is constituted by agriculture.

Besides heavy eutrophication caused by intensive agriculture and resulting in frequent oxygen depletion events, the estuary is strongly impacted by an intensive blue mussel commercial fishery. Furthermore, the fjord is used for ship transport from the North Sea to the Kattegat and vice-versa and water-related recreational activity (source: SPICOSA).

Fig. 2.1. The study site Limfjord, North Jutland, DK. (source: NERI)

3. METHODOLOGY

3.1. Categorisation of EGS

Many different methods for categorisation of ecosystem services have been defined (De Groot *et al.* 2002: Wilson *et al.* 2002; MEA 2003; Hein *et al.* 2006; Beaumont *et al.* 2007). For this study the over-arching classification of the benefits humans derive form the environment is drawn from the MEA (2003), a comprehensive assessment of the state of the global environment drawing upon the expertise of some 1300 scientists from around the world.

The MEA definition follows Constanza (1997) and it follows Daily in using the term "services" to encompass both the tangible and the intangible benefits humans obtain from ecosystems, which are sometimes separated into goods and services respectively (MEA 2003). In the MEA (2003) four categories of ecosystem services have been identified: provisioning (also referred to as ecosystem goods), regulating, supporting and cultural.

A fifth category included by Beaumont *et al*. (2007) and used in this study is option-use value:

- **Production services** are products obtained from the ecosystem.
- **Regulating services** biophysical processes controlling natural processes
- **Cultural services** are the nonmaterial benefits people obtain from ecosystems.
- **Option-use value** is the benefit associated with an individual's willingness to pay to safeguard the option to use a natural resource in the future, when such use is not currently planned.
- **Supporting services** are those that are necessary for the production of all other ecosystem services, but do not yield direct benefits to humans.

Within each category a range of goods and services has been identified (Table 3.1).

3.2. Identification of EGS provided by the Limfjord

The identification of ecosystem services provided by the Limfjord was carried out in a two-step approach and based on the "Expert opinion methodology" often applied in social sciences. Between August and October, semi-structured interviews and informal meetings were carried out with members of key stakeholder groups. In total 16 interviews with experts in ecology, economy and social science were conducted.

Table 3.1. Ecosystem Goods and Services

Category	Goods and Services
Provisioning services	1. Food provision 2. Raw materials 3. Genetic, medical and ornamental resources 4. Fresh water
Regulation services	5. Gas and climate regulation 6. Water regulation 7. Disturbance prevention (Erosion control) 8. Bioremediation of waste
Cultural services	9. Cultural heritage and identity 10. Leisure and recreation 11. Cognitive benefits 12. Feel-good (non-use benefit) 13. Future unknown and speculative
Option-use value	14. Primary production 15. Habitat provision
Supporting services	16. Nutrient cycling 17. Soil formation and retention 18. Resilience and resistance

Step 1: Telephone-survey

Prior to the telephone-survey SPICOSA Study Site partners were provided by e-mail with a consultation document explaining the theory of "Ecosystem goods and services" and containing the EGS-list with further explanations (Appendix I). Through the telephone-survey, a preliminary list of EGS was complied and experts and stakeholders for *Step 2* were identified.

Step 2: Interviews

The following experts and stakeholders were identified and are listed according to their field of expertise Table 3.2. Experts and stakeholders were contacted by e-mail and asked to set an appointment for a personal interview. The interviews were partly carried out during a 4-day visit to the Limfjord area Fig. 3.2.

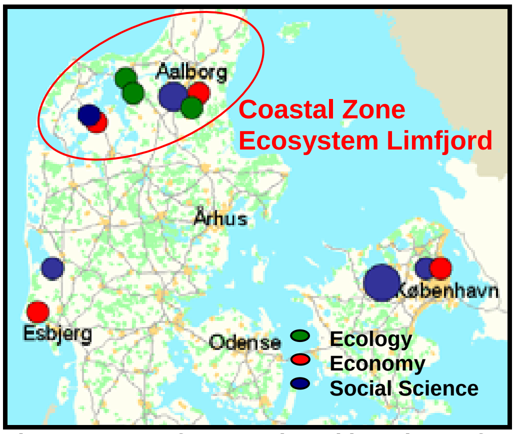

Fig. 3.2. Map of Denmark and locations of expert/stakeholder opinion interviews.

Table 3.2. Interdisciplinary list of experts

Expertise # interviewed	Interview Partner	Institute/ Organisation
Ecology		
#	Josianne Støttrup	DTU Aqua
#	Erik Hoffmann	DTU Aqua
#	Per Dolmer	DTU Aqua
#	Karen Timmermann	NERI
#	Stiig Markager	NERI
#	Jens K.Petersen	NERI
#	Marianne Holmer	SDU
#	Martha Laursen	RIN-MIM
	Bent Jensen	RIN-MIM
#	Jens Dendning	AAL-MIM
#	Finn Andersen	AAL-MIM
	Svend Å. Bendtsen	AAL-MIM
	Susanne Mortensen	AAL-MIM
	Svend Bråten	AAL-MIM
	Ditte Tørring	DSC
Economy		
#	Eva Roth	SDU
#	Sten Sverdup-Jensen	IFM
		IFM
#	Jesper Raakjaer	DSC
	Franz Højer	
Social		
#	Benny Andersen	DFA
#	Anders Bloksgaard	Limfjordmuseet
#	Thomas Olesen	Limfjordmuseet
#	Sten Sverdup-Jensen	IFM
		IFM
	Jesper Raakjaer	
Acronyms		
DTU Aqua	National Inst. of Aquatic Resources	
NERI	National Environmental Research Inst.	
SDU	University of Southern Denmark	
RIN-MIM	Environmental Center Ringkøbing	
AAL-MIM	Environmental Center Aalborg	
IFM	Innovative Fisheries Management	
DSC	Danish Shellfish Center	
DFA	Danish Fishermen's Association	

3.3. Characterization of EGS provided by the Limfjord

Once the major service types are identified, their ecological, economic and social attributes must be determined. According to the Ecosystem Services Framework (Daily 2000) an ecological characterization of ecosystem services is needed to inform decision-makers and would be used to assess the importance/ value, of ecosystem services in economic and other terms.

EGS are characterized on the basis of reports from Danish Research Institutes (DTU Aqua, NERI, RIN-MIM and AAL-MIM) and supplemented with information acquired during the expert/ stakeholder opinion interviews. Furthermore national online-databases: Statistics Denmark; Ministry of the Environment: National database for marine data (MADS), DTU Aqua-GIS: "Mussel production in the Limfjord", Danish Forest and Nature Agency; Danish Directory of Fisheries (DDF) and also international accredited journals were browsed for additional information on ecosystem services and their values.

3.4. Economic ecosystem valuation

3.4.1. Total Economic Value (TEV)

The overview over Economic valuation terminology and present Economic valuation techniques is derived from the article "Ecosystem Services" published by the British Parliamentary Office of Science and Technology (POSTnote, 2007): "*The Total Economic Value (TEV) conceptual framework views ecosystem goods and services as the flows of benefits to humans provided by the stock of natural capital. Values are assessed* *through the ways in which ecosystem services support people's own consumption (use values) and provide intangible human benefits (non-use values)*" (Fig. 3.3).

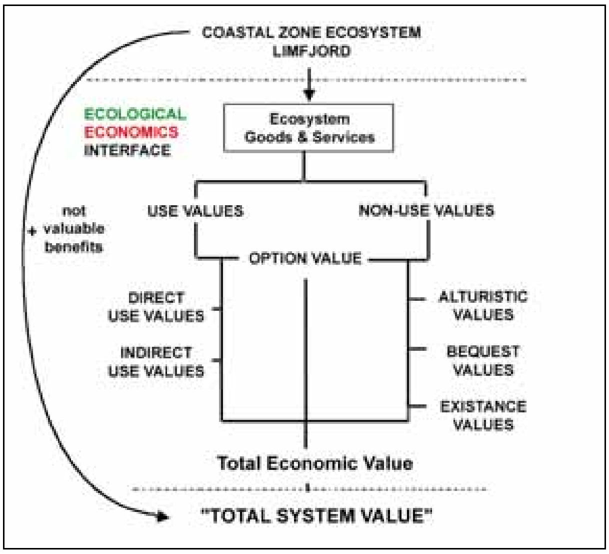

Fig. 3.3. The components of Total Economic Value and Total System Value.

Use values are subdivided into:

- *Direct-use values*: Values from direct human use of natural resources. These can be *extractive* use values from outputs such as timber or fisheries, and *non-extractive* use values from activities such as tourism and recreation.
- *Indirect use-values*. Values from regulatory processes that indirectly provide support and protection to human activities, such as flood protection.

Non-use values are subdivided into:

- *Altruistic values*: derived from knowing that others can enjoy the goods and services from ecosystems
- *Bequest values*: passing on ecosystem services intact to future generations
- *Existence values*: the satisfaction to humans from knowing that ecosystems continue to exist.

Option values

In addition to use and non-use values, ecosystem services may have option values in relation to possible but as yet unforeseen uses such as species with pharmaceutical applications.

Economic, deliberative and participatory methodologies are used to try to ascertain relevant values. These attempts to establish either an individual's willingness to pay (WTP) for an ecosystem service (or to avoid its degradation) or willingness to accept (WTA) compensation for the degradation of an ecosystem service (or foregoing an improvement or restoration of an ecosystem service).

3.4.2. Economic valuation methods

According to POST five main sets of methodologies are employed, which will be appropriate depending on the application and data available. The fifth method "Deliberative and participatory valuation" is not included in this work and instead "Benefit transfer" is explained.

a) Market price can be used to estimate the value of ecosystem goods and services that are traded in formal markets, such as timber and fish. The prices need to be adjusted for any market distortions. The benefit to society (economic value of activity) is the market price minus the cost of production).

*b) Cost based methods***,** based on the cost of damage caused by the loss of an ecosystem service (cost of providing substitute services), or expenditure to prevent that damage, or the cost of replacing the ecosystem service altogether.

c) Revealed preference methods based on surrogate markets; such as the travelling and access costs people are willing to pay to use an ecosystem for recreational purposes (Travel cost method) and the difference in (property or wage) prices that can be ascribed to the existence or level of nearby environmental goods and services (Hedonic pricing)

d) Stated preference methods such as surveys to determine people's WTP to pay for ecosystem services in hypothetical markets (Survey-based Contingent valuation method, CVM).

e) Benefits transfer. This method is used to estimate economic values for ecosystem services by transferring available information from studies already completed in other location and/or context. This method is often used when it is too expensive and/or too little time available to conduct an original valuation study, yet some measure of benefits is needed (www.ecosystemvaluation.org).

For further information see publications by the Environmental Economist Ståle Navrud and web-based BT databases (e.g. ENVALUE, EVRI)

3.4.3. Ecosystem valuation difficulties

Marginality

"*When it comes to valuation it is 'marginal' values that are required, rather than aggregated global values, which do not fit into formal cost/benefit appraisal systems and methods.*

At the margin, it is important to know what the value of lost ecosystem services is" (Turner *et al*. 2003). Because of the uncertainties surrounding threshold effects and the true extent of intact or relatively undisturbed global biomes, judging what is and what is not a 'marginal' change, for example, is a far from straightforward problem (Turner *et al*. 1998).

Double counting

"*Going beyond the 'marginality' problem, it is also important to identify sources of 'double counting' in any TEV study. In other words, many ecosystem services are not complementary; the provision of one is precluded by others. The full range of complementary and competitive services must be distinguished before any aggregated valuation is completed*." (Turner *et al.* 2003)

4. RESULTS

4.1. Identification of EGS provided by the Limfjord

During the telephone-survey the SPICOSA core-members identified a preliminary list of EGS. Through expert/ stakeholder interviews and discussions the list of EGS was completed (Table 4.1).

The assessment of EGS shows that the Limfjord provides a wide range of ecosystem goods and services; many of them having non-use values.

4.2. Characterization of EGS provided by the Limfjord

The identified EGS (Table 4.1) set the general framework for the characterization. EGS are defined in more detail by sub-categories (Table 4.2).

Table 4.1. Ecosystem Goods and Services provided by the Limfjord

Category	Goods and Services
Provisioning services	**1**. Food provision **2**. Raw materials
Regulation services	**5**. Gas and climate regulation **6**. Water regulation **7**. Disturbance prevention (Erosion control/ sediment retention) **8**. Bioremediation of waste
Cultural services	**9**. Cultural heritage and identity **10**. Leisure and recreation **11**. Cognitive benefits **12**. Feel-good (non-use benefit)
Option-use value	**13**. Future unknown and speculative benefits
Supporting services	**14.** Primary production **15**. Habitat provision **16**. Nutrient cycling **18**. Resilience and resistance

Table 4.2. Ecosystem services provided by the Limfjord and sub-categories.

Provisioning services	Sub-category

Food provision	• Commercial fishing:
	  • Blue mussel (*Mytilus edulis*)
	  • Flat Oyster (*Ostrea edulis*)
	  • Herring (*Clupea harengus*)
	• (extensive) Mariculture: Transplantation and relaying of Blue mussels
	• (different intensive) Long-line mariculture of Blue mussels

Raw material	Renewable biotic resource:
	• Industrial fishing:
	  • Sprat (*Sprattus sprattus*);
	  • Herring (if market price below minimum price)
	Non-renewable resources
	• Sand and gravel extraction

Regulation services	
Gas (and climate) regulation	• Carbon dioxide sink: Benthic vegetation
Water regulation	• Goods transport • Passenger ferries
Disturbance prevention	• Erosion control and sediment retention: benthic vegetation (Eelgrass *Zostera marina*)

Bioremediation of waste	Fjord is a nutrient filter and active transformer of nutrients: Nitrogen (N); Phosphorous (P) • Denitrification (N) and permanent burial (N, P) • Benthic micro-algae • Retention of nutrients in filter-feeding benthos
Cultural services	
Cultural heritage and identity **Cognitive benefits**	• Early habitation: Limfjord is an icon in Danish History • Maritime history: Trade • Traditional fishery: Eel (*Anquilla anquilla*) • Monitoring of nature and the environment • Environmental education • Scientific research • Expected future-uses: Food provision, Raw material…
Leisure and recreation	Domestic recreation and Leisure Tourism • Sailing • Summer cottages • Camping • Bathing/ Beaches • Recreational fishery: Sports and Household fishery • Other recreational activities: kayaking, canoeing, windsurfing, kite-surfing, bird-watching, cycling …
Feel good (non-use benefit)	Existence value and Bequest value of: Healthy environment • Biodiversity

Option-use value	
Future unknown and speculative benefits	• Provisioning services • Genetic and medical resources
Supporting services	
Primary production	• Pelagic PP: Phytoplankton • Benthic PP: Eelgrass, macroalgae, microscopic algal mats
Nutrient cycling	• Nutrient input: loading through water run-off, sediment remineralisation, exchange with open sea (North Sea) • Nutrient export: sedimentation/ permanent buria, production of biomass, exchange with the open sea (Kattegat) and denitrification
Habitat provision	• Coastal zone : Bird habitat, Seal habitat • Benthic flora and fauna (3-D habitat) : Eelgrass meadows and macro-algae assemblages, Blue mussel beds • Inorganic hard substratum: sand and gravel
Resilience and Resistance	Ecosystem “Health” • Biodiversity (Number of species, functional groups) • Complexity of food-webs

4.3 Provisioning services

4.3.1. Food provision

Definition: The extraction of marine organisms for human consumption (Beaumont *et al*. 2007).

Commercial fishing

The commercial fishing in the Limfjord consists of a large fishery exploiting the wild stocks of common mussels (*Mytilus edulis*) and oysters (*Ostrea edulis*) as well as fishing after herrings (*Clupea harengus*) for human consumption and industry fishing after sprat (*Sprattus sprattus*) for reduction to fish meal and fish oil (listed under “raw material”). Furthermore catching of European lobster (*Homarus gammarus*) has grown the last years, but the small population probably cannot supply the market in the longer term (Erik Hoffmann 2007, pers. comm.).

The traditional fishing after eels (*Anquilla anquilla*), cod (*Gadus morhua*) and flatfishes such as plaice (*Pleuronectes platessa*) and flounder (*Platichtys flesus*) is as good as stopped (Hoffmann 2005). The reduction of flat-fishes has been explained by the loss in habitat due to water hypoxia and also the strong predation by growing cormorant and seal populations (Hoffmann 2005).

Blue mussels (*Mytilus edulis*)

Commercial shell fishing in the Limfjord is a license regulated fishery based on dredging and bottom trawling. There are 51 licences issued and tied to these licences is a number of technical rules about boat size, ship draft, engine power and fishing gear. The fishing is furthermore regulated with daily and weekly quotas and each vessel is allowed to land 30 tons per day and 85 tons blue mussels per week in the Limfjord.

At present the annual landings are much lower than the total allowable catch based on a self-management regulation of the Danish Fishermen’s Association in 2005, which limits weekly catch to 45 tons (Bråten and Platz 2006). This is due to the fact that the blue mussel biomass has dropped drastically in the last 13 years (Fig. 4.1).

In consequence the landings had to be reduced to insure a sustainable exploitation of the natural stock. In 2006 total landings (30.000 tons) had a value of 43 million DDK.

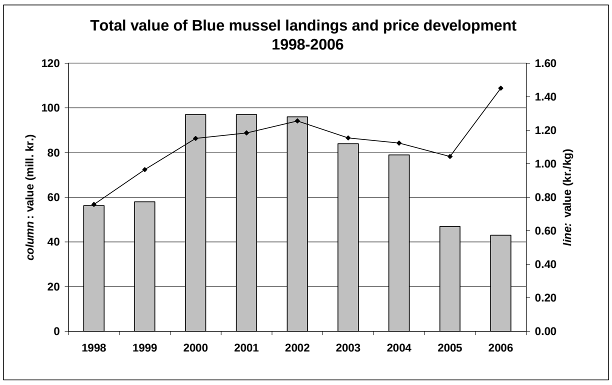

Fig. 4.1. Total value of Blue mussel landings and price development. Small quantities can result in abnormal high average prices. (Source: DDF. Note: Price values are not corrected for inflation)

The fishery for mussels is normally closed in December and January voluntarily and from the beginning of July to the end of August by law (Dolmer and Frandsen 2002; Hoffmann 2005).

The total area of 893 km² (Dolmer and Frandsen 2002) open to mussel-fishery is sub-divided into 42 area and in 2008 a reduction to 38 areas is expected (Benny Andersen, 2007 pers. comm.). On a weekly basis 6 areas are opened for fishing with a maximum of 10 vessels per area (Bloksgaard 2005).

The fishing after mussels presently employs around 80 (Bloksgaard 2005) to 100 (Benny Andersen, 2007 pers. comm.) fishermen with an average age of about 50 years. In total around the mussel industry creates around 500 jobs in the country (Bloksgaard 2005).

Blue mussel biomass

As mentioned earlier there has been an alarming drop in blue mussel biomass the last years, caused by a combination of lacking recruitment, water hypoxia and fishing (Hoffmann 2005). Between 1993 and 2003 biomass has dropped from 800.000 tons to 350.000 tons (Hoffmann 2005). A further significant reduction in biomass took place between 2004 and 2006, when biomass dropped from around 500.000 tons to approximately 150.000 tons (Fig.4.2).

According to Per Dolmer (DTU Aqua) it is difficult to rank the three reasons mentioned above. The fishery alone does not explain the drop in stock size because the resent reduction in catch to 45 tons week is regarded as to be sustainable to the size of the stock.

A significant drop in biomass can be caused by water hypoxia (Fig. 4.3). Water hypoxia in the Limfjord happens in two areas; Thisted Bredning and a large area starting in Risgaarde Bredning stretching south into Skive Fjord and Lovns Bredning and north up into Løgstør Bredning. The occurrence of water hypoxia showed a rising tendency in the period from 1989 to 2003 (Markager *et al*. 2006).

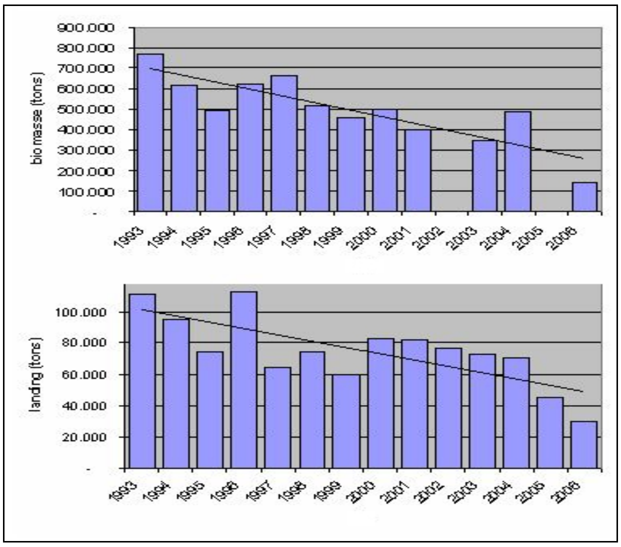

Fig. 4.2. Blue mussel biomass and landings in the Limfjord 1993-2006 (Data: DTU Aqua, Per Dolmer).

In 1997 about 350.000 tons died due to water hypoxia (Kristensen and Hoffmann 2004) and according to NERI the area affected was around 80 km^2.

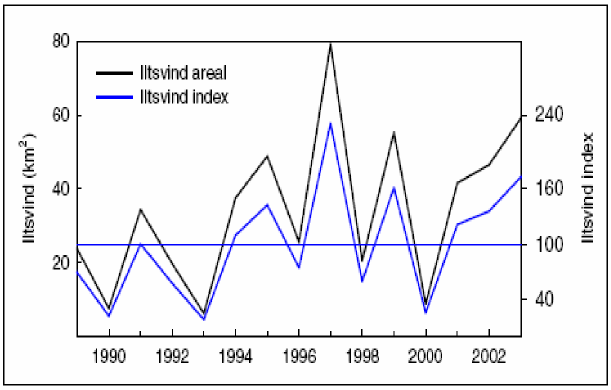

Fig. 4.3. Areas with oxygen depletion (oxygen conc. below 4 mg L^{-1}, averages for the period June-September) in the Limfjord. (Source: Markager *et al*. 2006).

To which extend the lacking recruitment influences mussel biomass is not known in detail.

Flat European Oyster (*Ostrea edulis*)

A second economically important bivalve fished in the Limfjord is the Flat European oyster (Fig. 4.4). The fishing after oysters is regulated in the same way as the blue mussel fishing with the exceptions that all bivalve vessels (51 boats) and 31 smaller boats with restricted licenses can dredge oysters only every second week (Bråten and Platz 2006). From the total area (892 km²) open to mussel fishery, the area affected by oyster dredging is around 246 km² (Kristensen and Hoffmann 2006). Total landings in 2006 were around 900 tons and with the high market price of 35kr./kg the landings had a value of 32 mill. kr. (Bråten and Platz 2006).

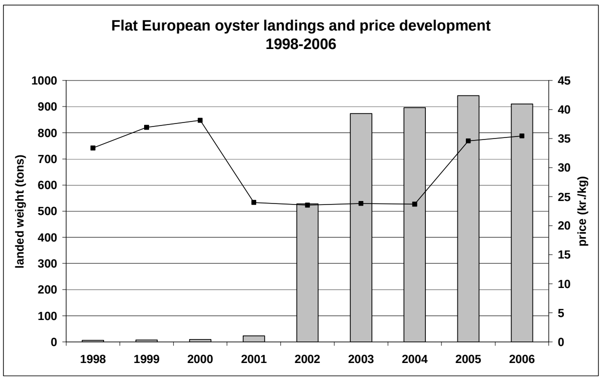

Fig. 4.4. Total landings of the flat oyster and price development from 1998-2006. (Source: DDF)

Flat European Oyster biomass

The total biomass of the Flat European oyster in the fished area is calculated to be around 3.500 tons with the highest abundance in Nissum Bredning (Kristensen and Hoffmann 2006) (Fig. 4.5).

Fig. 4.5. Biomass of *Ostrea edulis* in 2005. (Source: DTU Aqua-GIS).

In the last 5 years a strong increase in stock size was observed (Fig. 4.6).

The strong increase in population size is probably connected with a temperature increase (~1.5°C in 25 yrs), which has been registered in the summer period in the last 10 years (Bråten and Platz 2006; Kristensen and Hoffmann 2006); increase in salinity is also favourable to the growth of oysters. The larvae's survival is best at temperatures between 10 and 24 ºC.

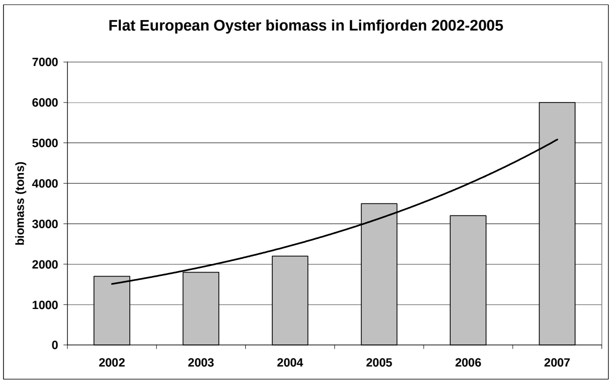

Fig. 4.6. Biomass of *Ostrea edulis* in Limfjorden (exponential line: y = 1184.7e0.2427x; R^2 = 0.8965) (Kristensen and Hoffmann 2006; year 2005+2006 DTU Aqua Notat 2007 not published yet).

The biomass is expected to show rising tendency, assuming warm summers and mild winters, which give good prospect for breeding and survival of larvae and young-stages (Kristensen and Hoffmann 2006). Almost a doubling in biomass has been observed from 2006 to 2007 (Fig. 4.5).

This almost exponential increase in biomass has positive and negative implications for the Danish mussel fishery. For the fishermen the increase in oyster biomass means an economically sustainable fishery in comparison to the reduced and further declining blue mussel fishery.

The increasing oyster stock size and density also has a direct negative effect on the blue mussel fishery, because blue mussel catches containing more then 1% oysters are not allowed to land. Nevertheless, this negative effect is bound to fishery regulations and will most likely result in a change of regulations when becoming a problem (Per Dolmer, 2007 pers. comm.).

Herring (*Clupea harengus*)

Herring is mainly caught for human consumption. The small fish species like sprat are "industrial landing", referring to landings resulting from fisheries directed upon and used exclusively for reduction to fish meal and fish oil. Nevertheless, Herring might finally end up being used for reduction to fish meal and fish oil. This could happen either because the fish could not be sold on the market (below the minimum price) or because the fish were rejected due to hygiene regulations (Yearbook of Fishery Statistics, 2005).

In the Limfjord six vessels are pair-fishing for herring (and sprat) in areas deeper than 6 m (Fig. 4.6).

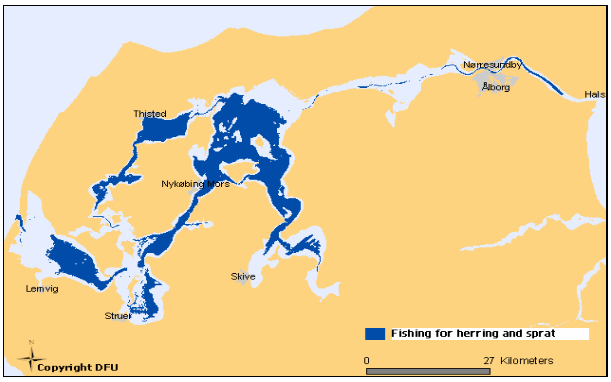

Fig. 4.6. Areas where fishery for herring and sprat is allowed (Source: DTU Aqua-GIS).

Regarding the Ecosystem goods and services classification herring is referred to as "food" and sprat will be further discussed under "raw material". Between 2004 and 2006 landings of Herring were around 5000-6000 tons/year (Fig. 4.7) and prices increased from relatively low 1,4kr./kg to 2kr./kg, corresponding to a value of 12 mill. kr. in 2006 (Fig 4.8).

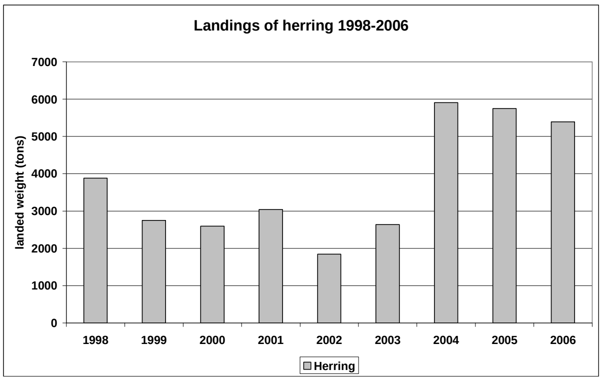

Fig. 4.7. Landings of Herring in the Limfjord 1998-2006. (Source: DDF)

The present Herring landings are higher than registered landings over the last 100 years. According to Erik Hoffmann increased landings are due to an increased immigration of the two stocks entering the Limfjord (North Sea stock and Kattegat stock) and a higher catch effort, represented by the highly effective method of pair-fishing.

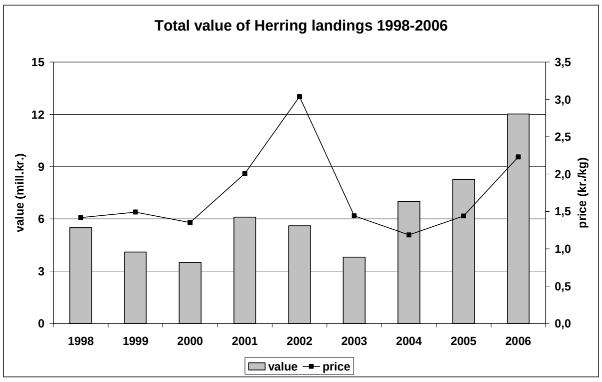

Fig. 4.8. Total value of Herring landings in the Limfjord 1998-2006. (Source: DDF)

Total value of landings

The total value of landings in 2006 was around 90 million kr. (year price), with blue mussel landings contributing 48 %, oyster landings 36 %, fish consumption landings 13 % and industrial landings 2-3 % (Fig. 4.9).

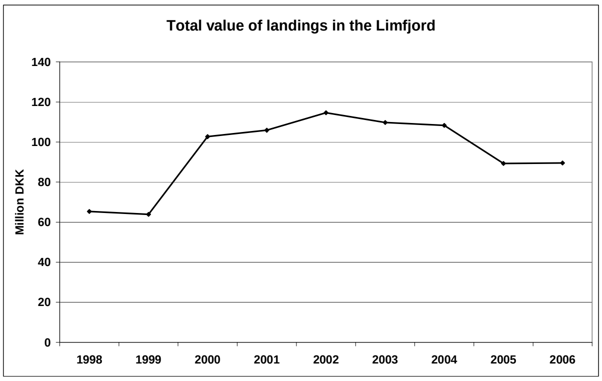

Fig. 4.9. Total value of landings in Limfjorden 1998-2006 incl. Blue mussel, Oyster, Sprat, Herring. (Source: DDF) Note: Year prices are not comparable, because they are not corrected for yearly inflation.

Aquaculture

Besides the fishing on wild blue mussel stocks different types and intensities of mariculture have developed According to the Food and Agriculture Organization (FAO) "*mariculture is the cultivation of an end product in seawater, such as fjords, inshore* and *open waters* and *inl*and *seas in which the salinity generally exceeds 20 ‰*."

In the Limfjord the following blue mussel production systems/methods are used:

- Transplantation
- Relaying of under-sized catch
- Long-line mariculture (2 methods).

Based on the Glossary of Aquaculture provided by the FAO the different production methods are supplemented with the aquaculture terminology that expresses the intensity of the activity (www.fao.org). Transplantation and relaying activities have been identified in this work as a mixture between "extensive to semi-extensive and capture-based aquaculture". The long-line mariculture is defined as "semi-intensive aquaculture, but with different grades of intensity according to the different methods used.

Transplantation of Blue mussels

As mentioned earlier the mortality of blue mussels due to oxygen depletion events has increased. This resulted in a series of experiments with new techniques such as the transplantation of small mussels from areas frequently exposed to oxygen depletion to areas (Kås Bredning) with a well oxidised and well mixed water column (Fig. 4.10) (Dolmer and Frandsen 2002).

The new technique proved to be successful and is now used in the Limfjord. "The benefits from this technique are multiple. There is an export of nutrients bound in mussel biomass from areas suffering from oxygen depletion to growth areas, where the transplanted mussels will accumulate nutrients from the water body until they are harvested and the nutrients are exported from the ecosystem. Furthermore, through this technique the mussels can be farmed in high densities and other areas can be permanently closed to mussel dredging, conserving the benthic flora and fauna in these areas."(Dolmer and Frandsen 2002)

Relaying of Blue mussels

A second type of production is the relaying of fished mussels below the legal landing size in certain plots (Dolmer and Frandsen 2002). (Fig. 4.10).

Fig. 4.10. Area open for transplantation and relaying of Blue mussels. (Source: DTU Aqua-GIS).

Long-line mariculture of Blue mussels

Whereas the transplantation and relaying of blue mussels represent a rather extensive aquaculture, the production of bivalves on long-lines represents a more controlled production system.

The two methods in use are of different intensities.

Method A:

- collection of spat on lines
- harvest of spat and sorting of size
- growing on long-lines.

Method B (also referred to as the "Swedish way"): is less labour intensive, because spat is not harvested during the growth period and mussels are first harvested when having reached full-size.

The following section will discuss long-line mariculture in general and does not distinguish between the 2 methods.

In 2006 a total of 407 tons of blue mussels, worth around 3 million kr. were produced by long-line mariculture (source: DDF). According to the Action plan 2006 for mussel production there are 38 operating farms and 34 applications (Fig. 4.11), and the number of bivalve aquaculture in the Limfjord are expected to rise powerfully in the years to come (Bråten and Platz 2006)

Fig. 4.11. Mussel farm permissions and applications in the Limfjord 2007. (Data: DTU Aqua-GIS).

The produced bivalves are of high quality due to their high meat content and are very suitable for the direct human consumption market. The produced bivalves can be sold to higher prices than the dredged mussels not only to their difference in quality but prices are also determined by time, quantity, market access, infrastructure and other parameters (e.g. eco-labelling) (Eva Roth, 2007 pers. comm.)

Nevertheless, the long-line mariculture does not show an economic surplus yet.

4.3.2. Raw material

Definition: The extraction of marine organisms for all purposes, except human consumption. Renewable (fish) and non-renewable (sand, gravel) resources will be included.

Industrial fishing/fish for reduction

The industrial landings consist usually of very small fish of the species sandeel, Norway pout, blue whiting, Atlantic horse mackerel or sprat, and may comprise legal by-catches of other species like herring. On the sales note from the industrial landing only the most dominant species of the catch are reported (Yearbook of Fishery Statistics, 2005).

Small size fish is reduced to fish meal and fish oil and used for aquaculture and farming. Landings show strong yearly variation but have been increasing constantly the last 4 years most likely due to new and highly effective catching methods as explained earlier (fig. 4.12).

In 2006 sprat landings, in total 2700 tons, generated a calculated value (based on 0,8 kr./kg as in 2004-2005) of 2 mill.kr. (Fig. 4.13). The price remained relatively constant and varied between 1.1 kr./kg in 1998 and 0.8 kr./kg in 2006.

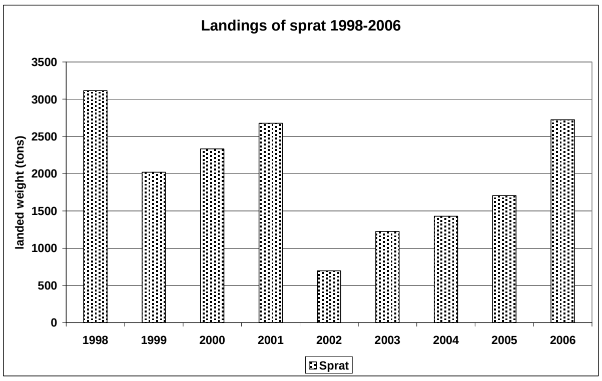

Fig. 4.12. Landings of sprat in the Limfjord 1998-2006 (Source: DDF)

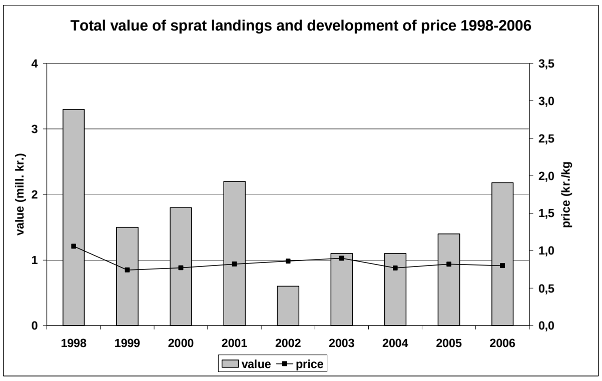

Fig. 4.13. Total value of sprat landings in the Limfjord 1998-2006. (Source: DDF)

Sand and gravel extraction

Extraction of raw material from the sea floor is highly regulated in Denmark. The areas open for extraction are geographically limited (Fig. 4.14)**.** and must have gone through an environmental assessment.

The permissions are issued by the Danish Ministry of the Environment (MIM), referring to the “Raw material law” § 20. Vessels used also need to be approved by the Ministry of the Environment referring to the “Raw material law” § 19. The areas open for raw material extraction are regulated according to the “Raw material law” §20. The permissions are limited to around 10 years, but can be extended on application.

Based on yearly reports from 1997-2002 it can be seen that mainly sand and gravel (6-300 mm) have been extracted from the sea floor (Table 4.3).

On average 50.000 m^3 sand and gravel have been extracted yearly between 1997 and 2002. Sand, gravel and stone are quality material and are mainly used for concrete and other products with the demand for special composition or purity. “Filling sand” is used for coast feeding and in connection with construction works and projects (see: Yearly report *Råstofproduktion i Danmark* 2006).

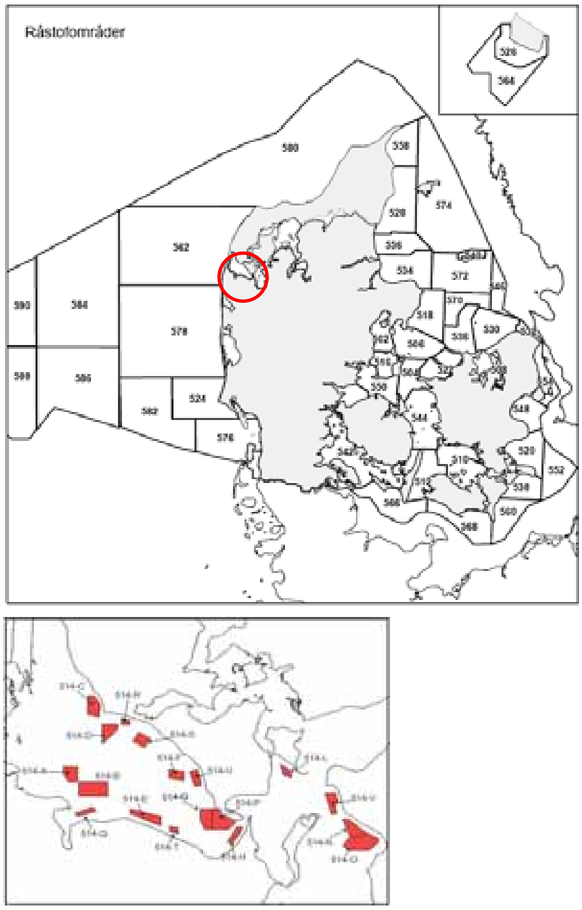

Fig. 4.14. Raw material areas before 2007 and close-up of the western Limfjord. (Source: MIM; also available on DTU Aqua-GIS)

Table. 4.3. Raw material extraction in the Limfjord 1997-2002 (unit = m³); sum of all areas. (Source: MIM). Note: In 2002 a large volume of filling sand was extracted in front of Hostrup Strand and Nygård Hage

Year	Sand	gravel	Sand and gravel	Filling sand
1997	0	0	44.430	0
1998	0	0	42.257	0
1999	0	215	55.035	0
2000	0	0	56.265	0
2002	0	1.130	48.635	55.252
Total	**0**	**150**	**50.390**	**55.252**

The geologist Poul Erik Nielsen from the Forest and Nature Agency of the Danish Ministry of the Environment gives the following information about raw material extraction in Limfjorden: "The extraction of sand and gravel in Limfjorden is now very limited. Permissions for extraction in Nissum Bredning expired December 2004, due to it's designation as an Special Protection Area (SPA) classified under the EC Wild Birds Directive, which is part of Natura 2000. In Venø Bugt four permissions expired in 2006. From 2007 there are only three small permissions in the area (Fig. 4.15).

Fig. 4.15. Sand- and gravel extraction in Venø Bugt, Limfjorden. (Source: Danish Forest and Nature Agency)

The permissions expire in 2009 but may be renewed. According to the permissions the total amount of sand and gravel extracted in the three year period must not exceed 60.000 m³. Total extraction in the areas January-June 2007 was 5.500 m³. The future extraction is expected to be limited. Maintenance dredging is frequently carried out in the eastern part of Limfjorden and on Hals Barre. A large part of the dredged sand is reused for production of concrete and as filling material in constructions".

4.4. Regulation services

4.4.1 Gas and climate regulation

> **Definition**: The balance and maintenance of the chemical composition of the atmosphere and oceans by marine living organisms. (Beaumont *et al* 2007)

CO_2 sink – benthic vegetation

Terrestrial and marine plants fix atmospheric CO_2 and return it via respiration. In the ocean, "the biological pump" acts as a net sink for CO_2 by increasing its concentration at depth, where it is isolated from the atmosphere for decades to centuries, causing the concentration of CO_2 in the atmosphere to be about 200 parts per million lower than it would be in the absence of life (MEA 2005).

The reduced emissions of greenhouse gases (CO_2) is a uniformly distributed global benefit (Dubgaard *et al*. 2003) and one tonne of sequestrated CO_2 is by Tim Taylor and colleagues valuated to be worth Euro 19 based on the marginal abatement costs for Europe (Tim Taylor, University of Bath, pers. comm.; Henriette Nortoft, Master thesis).

The Limfjord is considered to act as a carbon dioxide sink due to carbon burial in vegetated habitats like seagrass meadows (Duarte *et al*. 2005; Marianne Holmer, 2007 pers. comm.).

Vegetated habitats have been neglected from present accounts of the global ocean carbon cycle possible as a consequence of the limited extend of marine vegetation and the significantly rapid decline of area covered by sea grass meadows (Duarte 2005). Duarte and colleagues derived an estimate for carbon burial of 83 $gCm^{-2}y^{-1}$ for sea grass meadows (Fig. 4.16).

Already in 1981 Smith explained that due to slow turn over times of long-lived organisms such as seagrasses, marine vegetation holds a significant fraction of the autotrophic biomass therein (Duarte *et al*. 2005). The important role of vegetated coastal habitats in the ocean carbon budget is, however, eroded by the high losses experienced by these ecosystems.

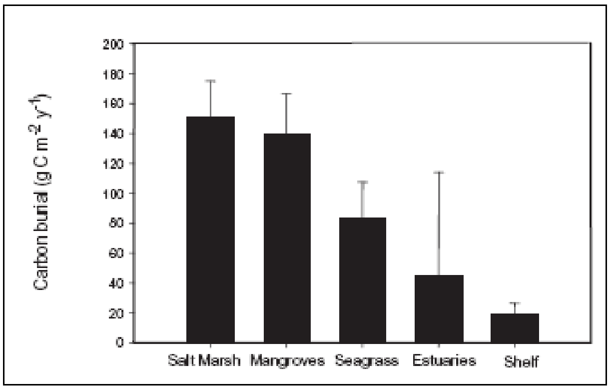

Fig. 4.16. Average (+SE) carbon burial rates in different coastal ecosystems. (Source: Duarte *et al*. 2005).

The area distribution of eelgrass in the Limfjord was estimated at 345 km^2 in 1900 (Ostenfeld 1908) and only at 84 km^2 in 1994 (based on aerial photography data from the Limfjord counties (NERI). At present the area coverage by eelgrass is even less, which can be seen when comparing maps of eelgrass distribution from 1994 (Fig. 4.17) and a GIS-map on the online-GIS databank of DTU Aqua based on monitoring data from the Limfjord County Authorities (Fig. 4.18).

The different methodologies underlying the eelgrass maps from 1994 and present make a comparison of values questionable and are thus just shown to stress the critical status of eelgrass in the Limfjord. Based on the NERI-data eelgrass coverage area from 1900 to 1994, Duarte´s estimated carbon burial of 83 $gCm^{-2}y^{-1}$ and Tim Taylors value of 19 Euro per sequestered ton CO_2 it can be calculated that the CO_2 -sequestration service of the eelgrass was worth 411 Euro more in 1900 compared to 1994 (Table 4.4).

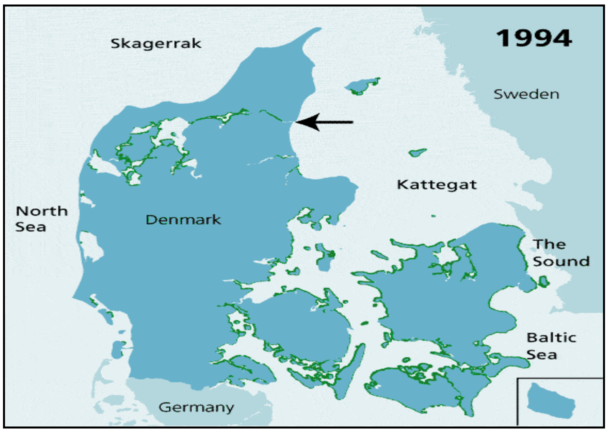

Fig. 4.17. Coarse map based on visual examination of aerial photos and data from the national Danish monitoring programme, produced Jens Sund Laursen (Source: NERI)

Fig. 4.18. Area cover of eelgrass in Limfjorden. (Source: DTU Aqua)

Table 4.4. Attempt to evaluate the cost of the lost CO_2 -sequestration service caused by a reduction eelgrass area service "CO_2 -sink" and loss due to decreased area distribution.

Year	Area distribution whole Limfjord [m²]	Value of CO_2 -sequestration [Euro/year]
1900	345.000	544
1994	84.000	133
Loss	261.000	411

This of course is just an attempt to value the CO_2 -sequestration by vegetated marine habitats based on the available data. Nevertheless, a "guesstimate" is better than no value, because vegetated marine habitats can thus be included in present accounts of the global ocean carbon cycle.

4.4.2. Water regulation

Definition: Provisioning of water for agricultural (irrigation) or industrial processes (mining) or transportation (Constanza *et al*. 1997).

Goods transport

Goods transport by ship has been of great importance historically and is now still important especially for industrial cities like Aalborg (Stiig Markager, 2007 pers. comm.). In Aalborg harbour good throughput in 2005 was 2.5 mill. tons. The oil harbour was the largest business area with 1.1 mill. tons, closely followed by the bulk-products and the container traffic was around 300.000 tons. Good transported generated 11 mill. kr. after tax and with a capital of 280 mill. kr. Aalborg harbour has high potential for future expansion (www.aalborghavn.dk).

The Port of Aalborg (Nordjysk Transport Center) is the natural goods junction for competitive transport chains between the North Atlantic, Scandinavia, the Baltic Sea region and the rest of Europe. As the regional port and transport centre in the European TEN network, the Port of Aalborg has a central location. From the Kattegat over Hals it is just one hour's sailing time to the East Harbour and 2 hours to the Central Harbour for ships with a draught of up to 9.4 m. From Thyborøn, at the mouth of the Limfjord in the North Sea, ships with a draught of up to 3.8 m can reach Aalborg within approximately 8 hours.

Since 1970 the Port of Aalborg has been the basis port for maritime traffic to Greenland and

is the destination for scheduled services to Bornholm, Norway, the North Atlantic and the rest of Europe (www.aalborghavn.dk).
Total through-put of goods over the last 10 years (1996-2006) were on average 7.4 mill. tons in the 20 seaports (Table 4.5) surrounding the Limfjord.

Table 4.5. Seaports surrounding the Limfjord (Source: Denmark Statistics: Good transport SKIP45.

Agger Havn	Mors-Thy, Næssund
Aggersund Havn	Nykøbing M. Havn
Branden Havn	Skive Havn
Fur Havn	Struer Havn
Hals Havn	Sundsöre Havn
Hvalpsund Havn	Thisted Havn
Kleppen Havn	Thyborøn Havn
Lemvig Havn	Venø Færgeleje
Løgstør Havn	Aalborg Havn
Mors-Thy, Feggesund	Aalborg Portland havn

Goods transported by cargo vessels international was on 10 years average around 74 % of total transport, cargo vessels national 29 % and transported goods by ferries (only national) is 11 % of total transport over the last 10 years (Fig. 4.19).

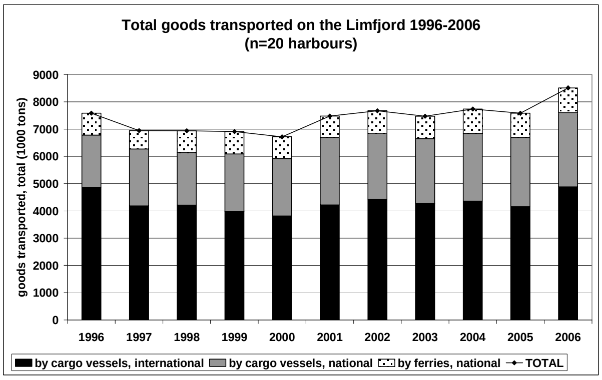

Fig. 4.19. Troughput of goods in the seaports surrounding the Limfjord 1996-2006. (Source: Denmark Statistics).

The area of the Limfjord used for shipping transport has been digitalized by DTU Aqua based on a sketch from the Royal Danish Administration of Navigation and Hydrograpy (RDANH) (Fig. 4.20).

Fig. 4.20. GIS-map of official ship transport routes in the Limfjord (Source: DTU Aqua).

Passenger ferries

The waterway *Limfjorden* transects the northern part of Jutland (Hoffmann, 1994). There are several bridges and ship connections between North Jutland and Mid Jutland. Transport on passenger ferries takes place at seven locations (Table 4.6). Prices are dependant on the unit transported and vary between the ferries (Table 4.7).

Table 4.6. Ship connections in the Limfjord. (Source: Denmark Statistics) and travel time.

Nr.	Passenger ferries	Travel time one-way
1	Thyborøn-Agger	10 min
2	Feggesund Arup	5 min
3	Kleppen-Venø	2 min
4	Stenøre-Branden	4 min
5	Rønbjerg-Livø	20 min
6	Hvalpsund-Sundsøre	10 min
7	Hals-Egense	5 min

Table 4.7. Range of prices charged on passenger ferries (Prices incl. return travel and are in Dkr.) Note on price ranges: Private cars: Small (S)– large (L). Lorries: S - with trailer. Bus excl. passengers: minibus (max. 8 pers.) - bus (> 25pers).

Nr.	Adult	Car	Lorry	Bus
1	24	108-198	180-374	100
2	20	100-148	170-250	95-240
3	15	.60-71	85-186	71-186
4	15	75	110-270	75-110
5	70	-	-	-
6	20	70-110	180-300	150-500
7	11	41-61	101-146	-

On a 10-years average around 1,8 million passengers every year were transported by passenger ferries. Cars (incl. private car, trucks and busses) transported by passenger ferries were around 780.000 cars/year from 1996-2006, where private cars accounted for more than 90 % of total car transport (Fig 4.21).

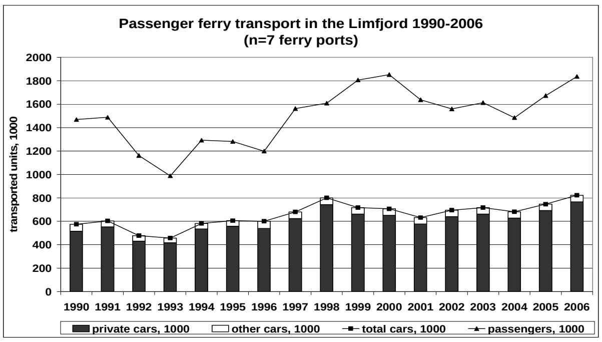

Fig. 4.21. Passenger ferry transport 1990-2006. (Source: Denmark Statistics).

4.4.3. Disturbance prevention

Definition: The dampening of environmental disturbances by biogenic structures. The disturbance alleviation service is provided mainly by a diverse range of species which bind and stabilise sediments and create natural sea defences, for example salt marshes, mangrove forests and sea-grass beds (Beaumont *et al*. 2007).

Erosion control and sediment retention

Along coastlines, macrophytes and macroalgae can reduce coastal erosion. Rhizomes and roots stabilize the sediment and leaves can reduce wave energy (Beaumont *et al*. 2007), so that seagrasses can reduce the erosion of the coastline (Nielsen *et al*. 2002a; 2002b). Both eelgrass and macroalgae reduce water movement over their stands, thereby increasing sedimentation (Read 1974; Ward *et al*. 1984 cited in Nielsen 2002a) and stabilizing the sediment they grow on (Borum *et al*. 2004).

According to Finn Andersen (AAL-MIM) coastal erosion does not represent a central problem regarding the whole Limfjord but might be of importance on a local level. Wind stirs up the water column and in shallow water areas sediment gets whirled up and conveyed. In a channel near Nibe, important for maritime transport, maintenance dredging produces higher costs than the building of streets in the area (Finn Andersen, 2007 pers. comm.). In earlier times eelgrass was present in the channel. Thus the costs for maintenance dredging represent one of the external costs caused by the loss of the eelgrass.

4.4.4. Bioremediation of waste

Definition: Removal of pollutants through storage, burial and recycling. Waste material can be organic, such as oil and sewage, as well as inorganic, comprising a huge variety of chemicals. Through either direct or indirect activity, marine living organisms store, bury and transform many waste materials through assimilation and chemical de- and re-composition (detoxification and purification processes) (Beaumont *et al*. 2007). Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients and compounds. The Limfjord is a highly eutrophicated water body and loading of excess nutrients (nitrogen and phosphorus) have negative effects on the whole ecosystem and will therefore be regarded as pollutants. Hence nutrient removal processes are included in the section "Regulatory services" and will only be shortly referred to under "Supporting services".

Limfjord as a filter and active transformer of nutrients

The Limfjord itself has a very important regulation function by acting as a nutrient-filter between the open ocean and land (Stiig Markager, 2007 pers. comm.).

Limfjorden´s environmental condition is to a very high degree controlled by the supplies of nitrogen and phosphorus. The surrounding area to the Limfjord is the most important source for nutrients but the atmosphere and the North Sea are also nutrient sources as can be seen in a 14-year average of the nutrient balance for the fjord (Fig. 4.22).

Denitrification and *permanent burial*

Excess nitrogen is removed through high denitrification (Seitzinger 1988; Stiig Markager 2007 pers. comm.) and permanent burial in the sediment.

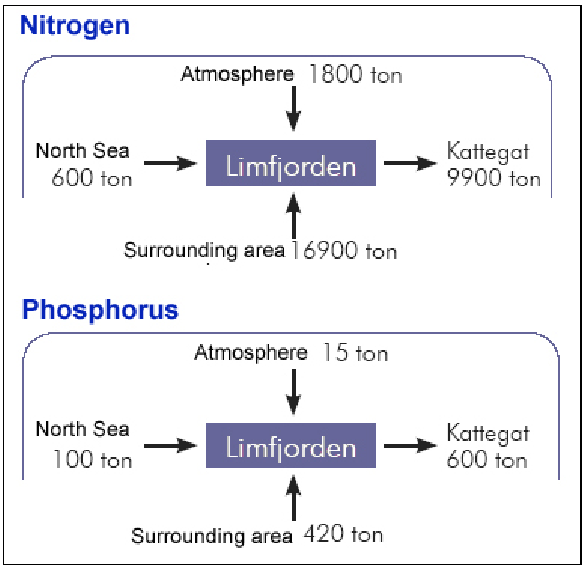

Fig. 4.22. Nutrient loading mass-balance for the whole Limfjord. (Source: Handlingsplan for Limfjorden 2006).

Based on Fig. 4.22 the fjord retains about 49 % of the added nitrogen. The yearly calculated nutrient balance by the fjord counties shows the filter capacity of the fjord in more detail. In 2004 the reduction of nitrogen due to sedimentation and denitrification accounted for around 37% of total input (Fig. 4.23).

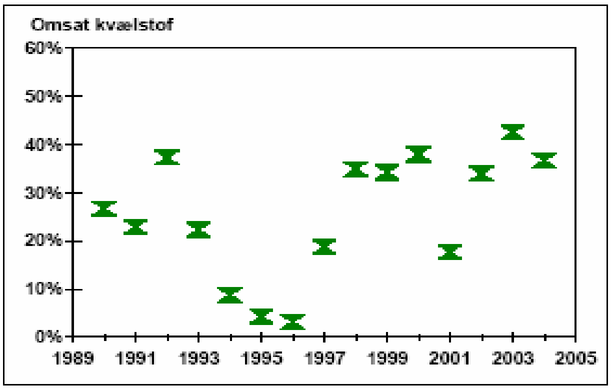

Fig. 4.23. Yearly sedimentation and denitrification of total-N in the Limfjord (% of the total N-input from the surrounding area, the atmosphere and neighbouring waters). (Source: Limfjordsovervågning 2004)

The retention of nitrogen in Danish estuaries has been found to be dependant upon estuarine residence times (Kaas *et al*. 1996; Conley *et al*. 2000). Highest denitrification rates are normally found during winter, when nitrate concentrations are at their maximum and good oxygen conditions favour coupled nitrification/ denitrification; denitrification is generally lowest during summer months (Rysgaard *et al*. 1995; Conley *et al*. 2000).

Phosphorus is removed through permanent burial in the sediment (Fig. 4.24). Phosphorous is not retained as efficiently as nitrogen in Danish estuaries (Kaas *et al*. 1996). The mass balance in Fig.4.22 shows that the supply of phosphorus to the Kattegat is bigger than the total supply to the fjord (~ 12% of total input). This is due to the fact that phosphorus is released from the bottom during events of water hypoxia. It also has been suggested that previously deposited P in sediments has a significant effect on internal loading of P in many Danish estuaries (Jensen and Holmer, 1994; Kaas *et al*. 1996; Conley *et al*. 2000). Nevertheless, despite occurrence of oxygen depletion, there was a net-sedimentation of phosphorus in 2004.

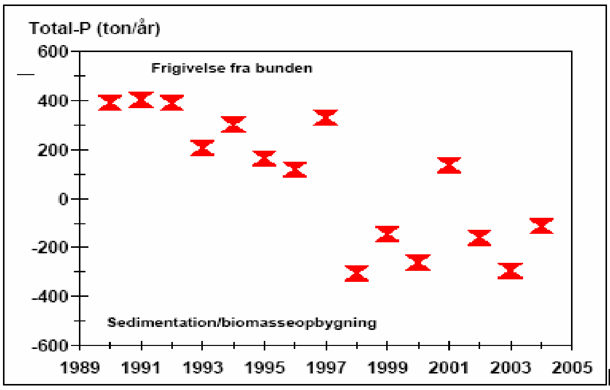

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Fig. 4.24. Yearly sedimentation and release of phosphorus in the Limfjord (tons/year). (Source: Limfjordsovervågning 2004).

Benthic microalgae

Sediment-water nutrient fluxes have a significant influence on the nutrient dynamics of Danish estuaries (Lomstein *et al*. 1998). Benthic algal mats and ephemeral macroalgae can act as filters for the sediment-water flux of nutrients. A demonstration of the influence of such filters was seen in Kertinge Nor, where a 6-fold increase in the sediment-water flux of nitrogen was observed from 1991 to 1992, after dense *Chaetomorpha linum* mats disappeared (Riisgård *et al*. 1995).

Benthic microalgae strongly regulate the flux of nutrients from or into the sediments, with marked influence on diurnal and seasonal variations in sediment denitrification processes (Rysgaard *et al*. 1995). Microalgae can act as an efficient filter, absorbing the flux of ammonium from the deeper, anoxic sediment layers. Rysgaard *et al*. (1995) concludes that benthic microalgae may have a strong regulating effect on the efflux of nutrients from the sediment surface to the overlying water in shallow estuarine waters.

Also it has to be mentioned that the capacity of the fjord to act as a nutrient-filter is highly dependant on climatic conditions. Wind forces determine the amount of water exchange and for most estuaries exchange with adjacent sea areas plays the major role for the flushing of the estuaries (Josefson and Rasmussen 2000). Furthermore, the variation in nutrient loading has in general followed the variation in freshwater runoff, with especially high concentrations in wet years (Josefson and Rasmussen 2000).

Retention of nutrients in filter-feeding benthos

The benthic faunal community has also been shown to retain nutrients (Josefson and Rasmussen 2000), with 25 % to 30 % of primary production passing through the benthic community (Conley *et al*. 2000). Bottoms in Danish estuaries are generally highly dominated by molluscs, often > 80 % of total biomass mostly bivalves.

Dominating bivalves are *Mytilus edulis, Cardium edule, Mya arenaria*, all filter feeders. In Halkaer Bredning, in the eastern part of the Limfjord, polychaetes made up a great part of the biomass (~25%) (Josefson and Rasmussen 2000). Since Danish estuaries are shallow, which may facilitate physical mixing of the water, the benthos has the potential to consume a large part of primary production. The biomass of *M. edulis* strongly influences the concentrations of chlorophyll in the water column (Fig. 4.25).

In Limfjorden, records on filtration capacity range from 23 to 180 $m^3m^{-2}day^{-1}$ (Riisgard 1991; Dolmer 2000 a, b) corresponding to a potential filtration of the whole water column several time a day (Dolmer and Frandsen 2002).

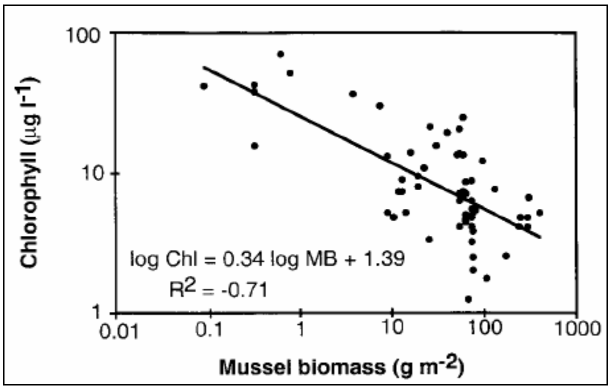

Fig. 4.25. The biomass of mussels and chlorophyll concentrations in April from Danish estuaries with a depth of 8.5 m from 1989 to 1995. (Source: Conley *et al*. 2000)

It is known that the filter feeder *M. edulis* retains nutrients in its living tissue and in particular nitrogen (Josefson and Rasmussen 2000). The fishing and harvesting of blue mussels makes it possible to export nutrients from the fjord (Lindahl *et al*. 2005). A sustainable fishery management has to ensure that mussel stocks can uphold this nutrient retention service. As explained by Dolmer and Frandsen (2002) a strategy of thinning the mussel beds instead of total exploitation would help to retain a constant benthic filtration and formation of biomass and consequently an improvement of the nutrient retention in the mussels.

The Danish Ministry of Food, Agriculture and Fisheries calculated that the harvest of 1 ton blue mussels will lead to a removal of 27.7 - 44.5 kg C, 6.4-0.4 kg N and 0.4-0.6 kg P. The lower value representing bottom fished mussels and the higher value representing long-line mussels with higher meat content (Table 4.8). These values contain an uncertainty in consequence of a great variation in the bivalves' condition and a poor documentation by the bivalves' nitrogen and phosphorous contents.

Table 4.8. Production of 1 ton living mussels can remove the following amounts (in kg) of organic carbon C, nitrogen N and phosphorus P. (Source: Handlingsplan fra Limfjorden 2006)

Fished mussels	**DW (meet)**	**C**	**N**	**P**
Estimate	50	22	4.7	0.3
Min.	35	11	2.5	0.2
Max.	70	35	7.7	0.4
	DW (shell)	**C**	**N**	**P**
	173	5.7	1.7	0.1
	154	5.1	1.5	0.1
	192	6.3	1.9	0.1
Total		**27.7**	**6.4**	**0.4**

Long-line mussels	**DW (meet)**	**C**	**N**	**P**
Estimate	90	39	8.5	0.5
Min.	60	19	4.2	0.4
Max.	150	65	17	0.9
	DW (shell)	**C**	**N**	**P**
	173	5.7	1.7	0.1
	154	5.1	1.5	0.1
	192	6.3	1.9	0.1
Total		**45**	**10**	**0.6**

In the Action Plan 2006 for the Limfjord focusing on mussel production it was estimated that 75.000 tons of fished mussels remove 480 tons of N and 30 tons of P (Table 4.9 + 4.10).

The blue mussels produced by long-line aquaculture have a higher meat content and therefore mussels are able to remove more nutrients A standard long-line farm (250*750 m) can yearly produce around 200 tons of mussels (Jens Kjærulf Petersen, 2007 pers. comment) and may remove 2 tons N and 0.1 ton P. It can be calculated that total mussel landings in 2006 (42 tons fished + 38 long-line farms) removed around 350 tons N and 21 tons P, corresponding to 2 % of total N-input and 5 % of total P-input.

Table 4.9. Estimated nutrient removal by fished mussels. (Source: Handlingsplan fra Limfjorden 2006)

Fished mussels (tons)	N-removed (tons)	P-removed (tons)	% of total nutrient input from the surrounding area***	
			N	P
200	1	0.1	0.01	0.02
10.000	64	4,0	0,38	0,96
25.000	160	10,0	0,95	2,39
50.000	320	20,0	1,91	4,78
75.000	480	30,0	2,86	7,18

*** average for the period 2000 until 2004

Table 4.10. Estimated nutrient removal by long-line mussels. (Source: Handlingsplan fra Limfjorden 2006)

Number of long-line farms	Long-line mussels (tons)	N-removed (tons)	P-removed (tons)	% of total nutrient input from the surrounding area***		Areal (km^2)	% of Limfjordens areal
				N	P		
1	200	2	0,1	0,01	0,03	0,2	0,01
10	2.000	20	1,2	0,12	0,29	1,9	0,13
20	4.000	41	2,4	0,24	0,57	3,8	0,25
30	6.000	61	3,6	0,36	0,86	5,6	0,38
40	8.000	82	4,8	0,49	1,15	7,5	0,50
50	10.000	102	6,0	0,61	1,44	9,4	0,63
100	20.000	204	12,0	1,21	2,87	18,8	1,25

*** average for the period 2000 until 2004

Nevertheless, it has to be considered that beside the potential of fishery to remove nutrients from the ecosystem, the nutrient retaining organisms are also removed.

4.5 Cultural services

4.5.1 Cultural heritage and identity

Definition: Benefit of biodiversity that is of founding significance or bears witness to multiple cultural identities of a community. There is benefit associated with marine biodiversity for example for religion, folk lore, painting, cultural and spiritual traditions. Human communities living by and off the sea often attach special importance to marine ecosystems that have played a founding or significant role in the economic or cultural definition of the community. (Beaumont *et al*. 2007). The concept of cultural services is relatively new and ecosystem provides cultural services only if there are people who value the cultural heritage associated with it (MEA 2003).

Early habitation

The fjords in Denmark are an icon in Danish history. In the Limfjord area (western Himmerland), signs of early settlement back to the Stone Age have been found and the Danish hunter/stone-age population is internationally known as the Ertebølle Culture (c. 5000 - 4000 BC) (www.stenaldercenter.dk).Through history people have established settlements along the coasts, and therefore, the estuaries are and have strongly influenced man activities for a long time (Conley *et al*. 2000).

Maritime history

Shipping has played an important role in Denmark since first people settled in the North Jutland area. People have exploited the fishing resources, to feed themselves, and also to trade. The Limfjord was an important water-way for trading goods in Northern Denmark.

The Limfjord Museum, in Løgstør, focuses exclusively on the Limfjord and preserves knowledge and information about the coastal culture and maritime history of the Limfjord area (yearly running costs ~1.7 mill. kr. in 2006; Anders Bloksgaard, 2007 pers. comm.). The Limfjord museum is housed in the former residence of the canal manager, built in connection with the construction of Frederik VII's Canal (1861-1913). Between 1898 and 1899 the largest number of ships passed the Canal: exactly 2.923 (Limfjord museum).

In the so called "Limfjordsmuseernes Samvirke" the Limford museum, the Thisted, Skive, Lemvig, Struer and the Fur museum cooperate in research projects that focus on the Limfjord's social and natural environment in the present and in the past.

Traditional fishery

Information about the condition of cultural services can be obtained by identifying the specific features of the ecosystem that are of cultural significance and then examining trends in those features. The condition of the cultural services from eel fishery could be linked to proxy measures (see MEA 2003) such as the value of eel-fishery landings.

Today the traditional fishery after the European eel (*Anquilla anquilla*) is as good as stopped (Hoffmann 2005). In earlier times eel-fishing was the financial most important fishery in Limfjorden (Hoffmann 2005).

Eel is a highly valued consumption fish and estimated values show that eel-fishery generated a 5 times larger income from landings in 1990 than in 2005 (Fig. 4.26).

Thus, assessing eel landings as a proxy measure for the condition of the cultural service it is clear that there had been a dramatic loss of the service.

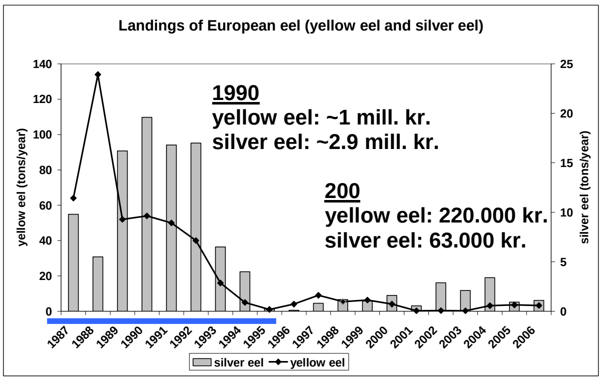

Fig. 4.26. Landings of European eel in Limfjorden 1987-2005. (Source: DDF; Hoffmann 2005).

Landings decreased first around the 1970s and again between 1992 and 1994, the period where the largest changes in Limfjorden's fish stocks took place (Hoffmann 2005). This is corroborated by data on recruitment and landings from the International Council for the Exploration of the Sea (ICES), which show a drastic decline from the end of the 1960s until today. Eel numbers stabilised briefly during the 1990s, according to both recruitment data and catch records, before declining to an all-time low of about 1 % of the 1960's population in 2001 (www.fishsec.org) Since 1996 a slight increase in "silver eel" landings could be observed but the positive tendency from almost nothing in 1996 to about 3 tons in 2004 (Hoffmann 2005) did not maintain and landings dropped in 2006 to 1 ton (Fig 4.26).

Eels decreased not only in Limfjorden but in whole Denmark; due to a strong decline in number of elvers normally reaching the Danish coasts. Whether this decrease is caused by a change in environmental factors (climate change, pollution), low recruitment due to over-fishing on the continental life stages in Europe or habitat loss/ blocking of migration routes is as yet uncertain (Hoffmann 2005; www.fishsec.org).

The traditional fishery after eel is just one example for a proxy that could be linked to a cultural service. The Limfjord in general experienced a strong decline in fish abundance. The dramatic decline in eel abundance might be due to factors outside the physical boundary of the CZ Limfjord but it nevertheless shows the same declining pattern that was observed for many other fish species (e.g. plaice, cod and flounder) (Fig. 4.27).

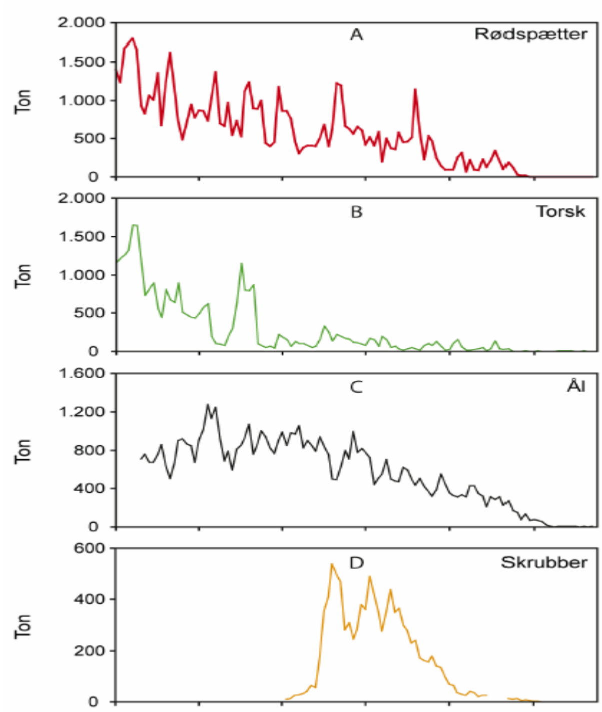

Fig. 4.27. Development of commercial fishing landings: A) plaice, B) cod, D) eel, E) flounder. (Source: Christiansen *et al*. 2006).

4.5.2. Cognitive benefits

Definition: Cognitive development, including education and research, resulting from marine organisms. In addition, marine biodiversity can provide a long term environmental record of environmental resilience and stress. The fossil record can provide an insight into how the environment has changed in the past, enabling us to determine how it will change in the future. This is of particular relevance to current concerns about climate change. Bio-indicators, such as changes in biodiversity, community composition and ecosystem functioning, are also beneficial for assessing and monitoring changes in the marine environment caused by human impact. Any expected future use is not option value, but would belong under cognitive benefits. (Beaumont *et al.* 2007)

Monitoring of nature and the environment

Since 1988 the former Limfjord county councils: Ringkjøbing Amt, Viborg Amt, Nordjyllands Amt have collected long time series of data during the monitoring programme *Limfjords-overvågningen*, which is part of the national monitoring programme.

Climatic data, hydrographic, physical and biological data have been recorded for more then 30 years. Data on water exchange, freshwater run-off and nutrient supply have been collected and analysed. Benthos, fish birds and seals data are available for over 10-20 years.

At present NERI coordinates the overall monitoring of nature and the environment in Denmark. NERI is responsible for monitoring of the air, open marine waters and a number of animal and plant species, while the county authorities are responsible for environmental monitoring of the groundwater, lakes, watercourses, fjords, coastal waters and terrestrial habitats (NERI). Since 1.1.2007 the national monitoring programme carried out by the county authorities has been renamed to NOVANA/ DEVANO and it will run over the next 3 years (AAL-MIM).

Over the online MADS database (NERI) large amounts of data are freely available: data about hydrochemistry, phyto- and zooplankton, primary production, benthic macrofauna, macrovegetation, sediment, contaminants, biomarkers and algal blooms in Danish waters.

Environmental education

Severe oxygen deficiencies in the Limfjord and its effects such as fish and shellfish kills, sea grass die-offs and release of hydrogen sulfide are highly discussed topics in local and national newspapers. In textbooks, television, news-papers etc. the Limfjord is often mentioned as a case example for an ecosystem that is heavily transformed and altered by human intervention (e.g. agriculture, fishing)

Furthermore hands-on environmental education is increasingly promoted. Several beaches in the Limfjord are awarded with the “Blue Flag”, which stand for: water quality, costal quality, safety, service and facilities, environmental education (information relating to coastal zone ecosystems must be displayed; environmental education activities must be offered) (www.blueflag.org).

Scientific research

The Limfjord has been and still is the subject of many research activities, including biological, social and economic studies. Research is supported by the close cooperation that exists between research institutes, universities, and managers from the counties bordering the fjord and stakeholders from different interest groups.

A series of national and international (EU) research projects have focused on the environmental status of the marine resources and the impact of present resource use. Many projects deal with sustainable aquaculture and potential new marine resources (DSC). Also Climate Change and its impact on the system and the possible change in goods and services are an important topic in present research studies.

Expected future - uses

Food provision and *raw material*

Beside the commercial fishing on blue mussels and oysters and the production of blue mussels in mariculture, large potential is seen in other shellfish species. The Limfjord has dense populations of e.g. American razer clam (*Ensis americanus*) and common cockles (*Cerastoderma edule*) (Dolmer and Frandsen 2002).

Furthermore, the high abundance of the European Green crab (*Carcinus maenas*) and the starfish *Asterias rubens*, inititated research projects (DSC) that focused on the usability of the European Green crab as a taste enhancer and the processing of starfish to fish meal and usage as an additive to animal food. The success of using these "new" species is dependent on the right technology, knowledge and of course a market for the product.

4.5.3. Leisure and recreation

Definition: The refreshment and stimulation of the human body and mind through the perusal and study of, and engagement with, living marine organisms in their natural environment. Marine biodiversity provides the basis for a wide range of recreational activities including: (sea) bird watching, rock pooling, beachcombing, sport fishing, recreational diving, and whale-watching. The provision of this service results in significant employment opportunities (Beaumont *et al*. 2007). Eco-tourism, sport fishing and other outdoor recreational activities (Constanza *et al*. 1997).

Recreation and tourism uses of ecosystems are growing, due to growing populations, greater leisure time available among wealthy populations, and greater infrastructure development to support recreational activities and tourism (MEA 2005). The Limfjord has a high importance as a local leisure and recreation area and it there is high potential for development of sustainable national and possibly international tourism.

Tourism

The World Tourism Organization (UNWTO) defines tourists as "persons travelling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes" and it is distinguished between Same-Day Trip ("Visitors who do not spend the night in a collective or private accommodation in the place visited") and Overnight Trip ("Visitors who stay at least one night in a collective or private accommodation in the place visited").

A ***Leisure tourist*** is defined as a person that travels for pleasure and thus is not under any obligations for frequent specific destinations or facilities. They tend to be price and fashion conscious, concentrate their touristic activities to specific (vacation) times, and are influenced by marketing and publicity. Leisure tourism is heavily influenced by living standards, discretionary income levels and vacation entitlements (Singapore Tourism Board, STB). The definition of Leisure tourism excludes Business Travel, which is defined as travel for commercial, governmental or educational purposes with leisure as a secondary motivation (STB).

In the following leisure and recreation activities it is not distinguished between domestic recreational use of the fjord and tourism due to limited data.

Sailing

The Limfjord is a very popular sailing area, nationally and internationally. At present the Limfjord municipalities Lemvig, Struer, Skive, Viborg, Vester Himmerland, Alborg, Jammerbugt, Thisted an Morsø have in total 64 harbours; 3 more than in 1997 (Fig.4.27).

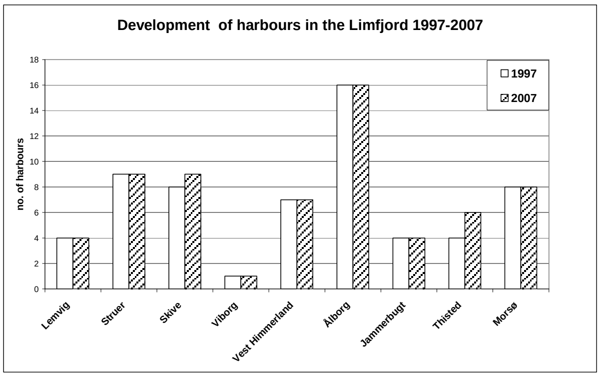

Fig. 4.27. Limfjord municipalities and number of harbours 1997-2007. (Data collection through telephone interviews by Asger Stensig Køppen, SDU Esbjerg)

In 2007 a total of 5069 sailing yachts have been registered this is around 25% more than in 1997 with 4077 registered sailing yachts (Fig. 4.28). Aalborg being the largest city around the Limfjord also has most harbours. The 16 harbours of Aalborg account for around 37% of all yachts registrations in 2007. In Struer und Skive harbours around 30% of ships were registered, in both municipalities harbour numbers increased.

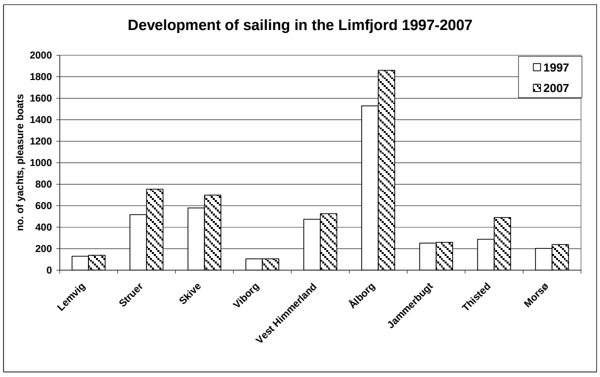

Fig. 4.28. Limfjord municipalities and total number of sailing yachts /pleasure boats for 1997 and 2007. (Data collection through telephone interviews by Asger Stensig Køppen, SDU Esbjerg)

Many municipalities wish to extend their marinas due to expected increasing sailing activity, interpreted from the long waiting lists reported by many harbours (SDU-Esbjerg).

Beside the increasing demand for boat places some of the municipalities experienced a large increase in guest overnight stays. In total (all municipalities) 14.600 guests stayed overnight in 1997, whereas in 2007 around 45 % more guests were registered (Table 4.11).

The overnight stays increased significantly in the last 10 years and the municipalities Jammerbugt, Lemvig, Aalborg, Struer, Skive and Morsø experienced the largest increases.

Table 4.11. Guests staying overnight at municipalities ´harbours in 1997 and 2007. (Data collection through telephone interviews by Asger Stensig Køppen, SDU Esbjerg).

Municipality	1997	2007
Lemvig	1600	3085
Struer	1710	2440
Skive	1900	2550
Viborg	100	100
Vest Himmerland	960	960
Ålborg	4725	8427
Jammerbugt	100	1100
Thisted	1720	1720
Morsø	1800	2200
Total	**14615**	**22582**

Holiday cottages

Holiday cottages are very popular in Denmark. In whole Denmark around 200.000 holiday homes are owned privately and 40.000 are let out to tourists (www.visitnordjylland.dk). In North Jutland holiday houses are available all year round. The total number of holiday cottages in the Limfjord area is not known in detail but according to an internet-based search the number of available cottages ranges from around 700-1000 in winter and goes up to 2200 in summer. Cottages prices for one week range from 3000 to 8000 kr. for 2 persons and can go up to 20.000 kr. for 16 persons (www.sommerhusudlejning-i-danmark.dk).

Camping

In Denmark more than 500 camping and caravan sites are registered. Based on an internet search around 46 camping sites bordering the Limfjord were counted (source: Asger Stensig Køppen, SDU Esbjerg).

Most camping sites are open in the spring/autumn season (April-September) but also all-year camping has become quite popular, many camping sites offer caravans and small cottages for rent all year-round. Prices per day for adults range from 50 kr. (low season) to 70 kr. (high season); children usually pay around 50 % and place fees are on average 20-25 kr. per day. Place capacities of the camping sites range from 50 to 880 persons (source: www.dk-camp.dk) (Fig. 4.29).

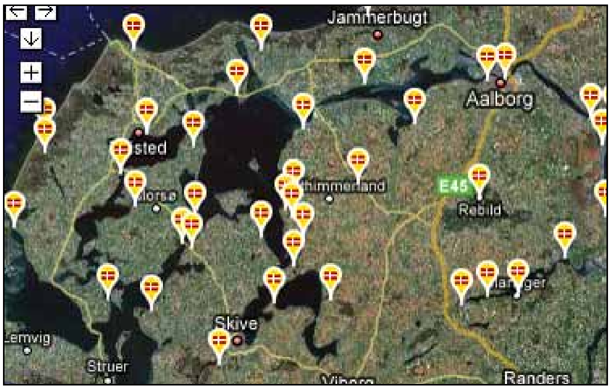

Fig. 4.29. Camping sites around the Limfjord. (Source: www.dk-camp.dk)

Bathing/beaches

There are plenty of opportunities along the 1000 km of the Limfjords coastline to enjoy a refreshing bath; especially during the summer months from May to August (Fig. 4.30).

Based on an online survey it was possible to list 38 beaches/ bathing areas bordering the Limfjord (source: VisitNordjylland). Almost half of the beaches have been advertised as being suitable for windsurfing, pointing out the demand for recreational activity areas (see: *other recreational activities*)

Fig. 4.30. Beaches (with 500m buffer zone) bordering the Limfjord. (Source: DTU Aqua-GIS).

Recreational fishery

Many people enjoy recreational fishing – especially angling – as sport or just to relax. In Denmark there are about 450.000 people engaged in recreational fishing activities (Eva Roth, 2007 pers. comm.). Most of them are angling (DFF).

Sports Fishery and Household Fishing are non-professional fishery activities without an income from fishing. For both activities there exist certain rules like the obligatory purchase of licences and limitations concerning fishing gear.

Sports fishery (Lystfiskeri, Sportsfiskeri)

Angling includes only the use of lord and line. The licences cost 125 kr. for a year, 90 kr. for a week and 30 kr. for a day (DDF). The number of registered sports fishermen with addresses in the municipalities, bordering the Limfjord was in the years 1995-1997, 10.673, 10.442 and 11.200 respectively. These numbers do not include non-registered fishermen with day-/or week licences, children below 18 years and adults over 67 years (Plan for fremtidens fiskeri i Limfjorden, 1999).

Household Fishery (Fritidsfiskeri)

Only Danish residents and members from EU countries with a special attachment to Denmark can buy household fishing licences (Eva Roth, 2007 pers. comm.) The price for a hobby fishing licence is 250 kr. for a year; the licence is also valid for angling. You have to be 12 years old to go hobby fishing; there is no upper age limit (DDF). The number of registered hobby fishermen with address in the municipalities bordering the Limfjord was between 1995-1997, 3.474, 3.194 and 3.234 respectively. Hobby fishing is mostly concentrated on flatfish species and eels.

Sea trout *(Salmo trutta trutta)* is caught both by sports anglers with a line and by household fishermen with fixed traps. As catches from recreational fishery do not have to be reported, there are no official statistics over the catches available. Calculations, however, show that the catching of trout lies around 65-70 tons annually (Plan for fremtidens fiskeri i Limfjorden, 1999). It has been reported on the official website of the sport fishermen that fishing after sea trout was very popular and successful especially in the spring of 2007 in the eastern part of the fjord (www.sportsfiskeren.dk).

Flounder *(Platichthys flesus)* and eel (*Anquilla anquilla*): Hobby fishermen catch both flounders and eels but since the abundance of both fish is considerably low, fishing effort is limited.

Lumpsucker (*Cyclopterus lumpus)* is fished both by anglers and hobby fishermen. The fish is valued for its eggs, which is known as "Limfjordskaviar". Fishing takes place especially in the western part of the fjord. In 1960 more than 100 tons were landed annually. Since the end of the 1970s a strong fall has been recorded and in 1995 only 32 tons were landed. Even though the fishing has declined, it is however still of local importance (Plan for fremtidens fiskeri i Limfjorden, 1999).

Garpike *(Belone belone)* is also highly valued by recreational fishermen and fishing takes place in early spring. According to online reports fishing after garpike has been quite successful this year especially in the eastern part of the fjord, Nørresundby and Aalborg (www.sportfiskeren.dk).

An outstanding survey about the "Economic value of recreational fisheries in the Nordic countries" based on the Contingent Valuation method has been made in 2000 (Toivonen *et al*. 2004)

Other recreational activities

The Fjord also holds the possibility for a wide range of recreational activities especially water sports such as windsurfing, kite-surfing, canoeing, kayaking, rowing, snorkelling and diving but also bird-watching, hiking and cycling are popular outdoor activities that include enjoying the beautiful nature. The *Limfjordscenter* in Thy offers a wide range of outdoor activities (www.limfjordscenter.dk).

4.5.4. Feel good

Definition: Benefit which is derived from marine organisms without using them. The current generation places value on ensuring the availability of biodiversity and ecosystem functioning to future generations. This is determined by a person's concern that future generations should have access to resources and opportunities. It indicates a perception of benefit from the knowledge that resources and opportunities are being passed to descendants (Bequest value). People derive a benefit, often reflected as a sense of well being, of simply knowing marine biodiversity exists, even if it is never utilised or experienced, people simply derive benefit from the knowledge of its existence (Existence value) (Beaumont *et al*. 2007).

"Healthy environment"

Biodiversity

The feel-good benefit people derive from an ecosystem is an explicitly non-use benefit. It depends on people's perception of the ecosystem and what good/ service of the ecosystem are of values to them. Beside this subjective approach the availability of biodiversity and ecosystem functioning is also an ethical issue in the context of Intergenerational equity, which says that "each generation has the right to inherit the same diversity in natural and cultural resources enjoyed by previous generations and to equitable access to the use and benefits of these resources" (Earth and Peace Education Associates International, EPE).

According to Stavros Dimas the Commissioner for Environment of the European Commission there is a profound social change in the perception of marine life. "People pay more and more attention to marine life and there is an increasing demand to exploit marine resources in a sustainable way. This profound social change, which will gather momentum in the coming years as the use of coastal and offshore areas becomes more and more diversified (Brown 2006).

Also regarding the Limfjord there is a strong interest in the conservation and restoration of the ecosystem on a national and international level (www.spicosa.org).

4.6. Option-use values

4.6.1. Future unknown and speculative benefits

Definition: Currently unknown potential future uses of marine biodiversity. Potential future uses of marine biodiversity have an option use value. Option value reflects the importance of more uses being discovered in the future. The biodiversity may never actually be exploited, but there is benefit associated with retaining the option of exploitation. Any expected future use is not option value, but would belong under cognitive benefits (Beaumont *et al.* 2007).

Provisioning services

A wide variety of species – microbial, plant, and animal- and their genes contribute to commercial product in industries such as pharmaceuticals, botanical medicines, crop protection, cosmetics, agricultural seeds and a series of other sectors (MEA 2005).

Genetic resources

The provisioning service "Genetic resources" includes the genes and genetic information used for animal and plant breeding and biotechnology (MEA 2005). Biodiversity supplies humans with genetic resources. Animals, plants and bacteria contain vast genetic information and the nowadays strongly developing biotechnology and molecular genetics now makes it possible to get access to this "genetic library" and make use of it.

Biochemicals, pharmaceuticals and natural medicines

This provisioning service refers to the many medicines, biocides, food additives such as alginate, and biological materials that are (or in this context could be) derived from the ecosystem (MEA 2005).

Turning to medicinal resources, a recent survey showed that of the top 150 prescription drugs used in the United States, 118 are based on natural sources: 74 % on plants, 18 % on fungi, 5 % on bacteria, and 3 % on one vertebrate (snake) species (MEA 2005). Demand for biochemicals and new pharmaceuticals are growing but new synthetic technologies compete with natural products to meet the demand (MEA 2005).

4.7.1. Primary production and nutrient cycling

Definition: Supporting services are those that are necessary for the production of all other ecosystem services. They differ from provisioning, regulating, and cultural services in that their impacts on people are either indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people. (Some services, like erosion control, can be categorized as both a supporting and a regulating service, depending on the time scale and immediacy of their impact on people). Examples of supporting services are primary production, nutrient cycling, provisioning of habitat (MEA 2003) and resilience and resistance (Beaumont *et al*. 2007).

Primary production

Primary production is an important supporting service since the biomass producing organisms form the base of the food chain and thus strongly influence many other services. Data on Primary production have been collected over many decades and are available on "The national database for marine data" (MADS) provided by NERI.

Basically it can be differentiated between *Pelagic primary production* (Phytoplankton) and *Benthic primary production* (Eelgrass and Macroalgae).

Pelagic primary production

The Limfjord is a eutrophic coastal water body and thus has characteristically high seasonal net primary production of phytoplankton. The seasonality of the primary production is the result of a strong seasonal signal in freshwater run-off (nutrient-input), temperature and salinity. Plankton and water samples for primary production measurements are collected several times during the year at three stations:

Nissum Bredning, Løgstør Broad and Skive Fjord (Fig. 4.31).

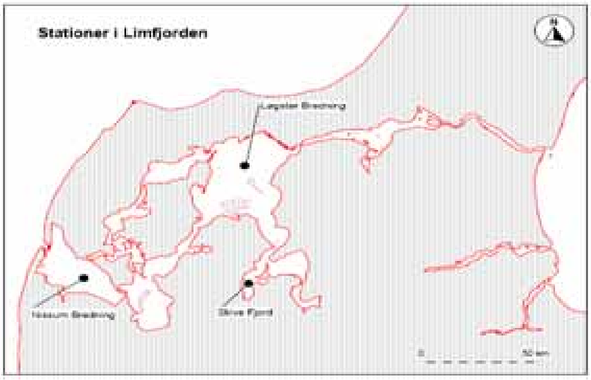

Fig. 4.31. Phytoplankton stations in Limfjorden (Source: Limfjordsovervågning 2003)

In Danish estuaries and coastal areas primary production has decreased from 1980 to 1997 and subsequently increased during 1998-2001. For the period 1993-2001 primary production was significantly correlated with runoff, irradiance and temperature. Index values adjusted for variations in climatic conditions showed a very consistent decline after 1993 (Fig. 4.32).

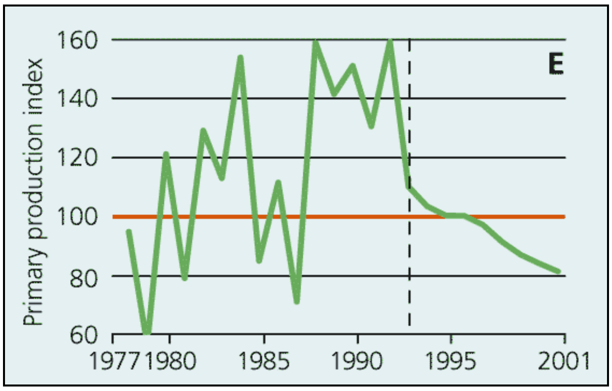

Fig. 4.32. Indices for annual primary production in estuaries and coastal waters, adjusted for variations in climatic conditions. Adjustments for climatic variations are developed on data from 1993–2001, but applied on data in all years. (Source: NERI).

The decline in primary production was presumably due to reduced phosphorus loading to the estuaries through the establishment of sewage treatment plants in the late 1980s and early 1990s and subsequent reduction in the nitrogen load both from point and diffuse sources (NERI).

Concerning the supporting function of primary production for other services (e.g. food provision) it is also of importance to consider the phytoplankton community composition. It has been shown that dominance of diatoms is more favourable for the food chain than dominance of non-diatoms (Schelske *et al.*, 1983; Smayda, 1990; Smayda, 1997; cited in Møhlenberg *et al.* 2003). If diatoms dominate, the PP is more easily transmitted towards higher trophic levels, leading to beneficiary secondary production (Møhlenberg *et al.* 2003).

Nutrient cycling

Nutrient cycling is defined as the storage, cycling and maintenance of nutrients by living marine organisms. Nutrient cycling encourages productivity, including fisheries productivity, by making the necessary nutrients available to all levels of the food chains and webs. (Beaumont *et al*. 2007).

The seasonal change in the balance between input (loading, sediment remineralisation, and exchange with open sea) and export (sedimentation, production of biomass, exchange with the open sea and denitrification) gives a characteristic pattern in nutrient concentrations.

Nutrient concentrations follow a seasonal pattern (Fig. 4.33). During winter, when nutrient loading is high and biological activity relatively low, concentrations of nutrients are correspondingly high. Throughout spring, uptake by primary producers transforms nutrients (nitrogen, phosphorous) from inorganic to organic forms. Concurrent with the decrease in loading, sedimentation of the spring phytoplankton bloom and commencement of macroalgae growth in late spring, nutrient concentration decrease (Conley *et al.* 2000).

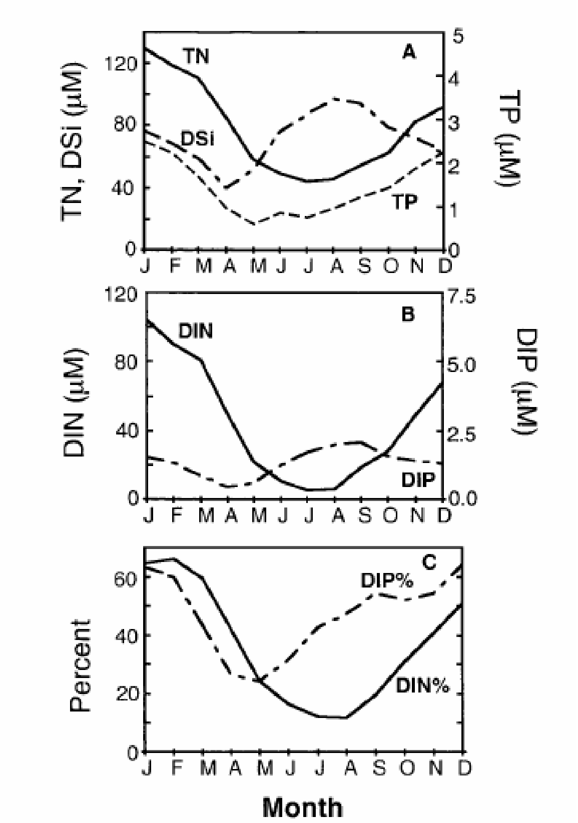

Fig. 4.33. Seasonal variation in nutrient concentrations in 33 estuaries during the period 1989 to 1994. A) Monthly mean concentrations of total nitrogen (TN), total phosphorus (TP), and dissolved silicate (DSi). B) Monthly mean concentration of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate (DIP). C) Monthly fraction of total nitrogen that is dissolved inorganic nitrogen (%DIN) and fraction of total phosphorus that is dissolved inorganic phosphate (%DIP). (Source: NERI)

Sediment-water nutrient fluxes have a significant influence on the nutrient dynamics of Danish estuaries (Lomstein *et al*. 1998). In addition, bioturbation by benthic fauna has a large influence on the regeneration of organic material in marine sediments (Andersen and Kristensen 1995). Benthic production of microalgae (Rysgaard *et al* 1995) and beds of rooted macrophytes (Risgaard-Petersen *et al* 1998) can also influence the sediment-water nutrient fluxes by acting as nutrient filters (Conley *et al.* 2000).

Denitrification is an important process in Danish estuaries and can remove a significant portion of the TN load (Rysgaard *et al.* 1999), although the proportion removed through denitrification is dependent upon the estuarine flushing time (Nielsen *et al*. 1995 &Kaas *et al.* 1996 cited in Conley *et al.* 2000).

4.7.2. Habitat provision

Definition: Habitat which is provided by living marine organisms. Many organisms provide structured space or living habitat through their normal growth, for example, reef forming invertebrates, meadow forming sea grass beds and marine algae forests. These "natural" marine habitats can provide an essential breeding and nursery space for plants and animals, which can be particularly important for the continued recruitment of commercial and/or subsistence species. Such habitat can provide a refuge for plants and animals including surfaces for feeding and hiding places from predators.

Living habitat plays a critical role in species interactions and regulation of population dynamics, and is a pre-requisite for the provision of many goods and services (Beaumount *et al*. 2007).

In this work the habitat function of the CZ of the Limfjord and hard bottom structures such as sand, gravel and stone reefs are included because they are of high importance in the present ecosystem and have been extensively used and exploited over many decades.

Coastal zone

Bird habitat

The CZ of the Limfjord is an important breeding habitat for many national and international important bird species and also plays a crucial role for migrating birds that use the area as "fuelling-up" station on their way from South to North (Finn Andersen, 2007 pers. comm.). To get an overview over bird species and to assess the importance of the Limfjord for breeding and migrating birds the Natura 2000 protected sites and areas served as the main reference.

The legal basis for the Natura 2000 habitats is the EU birds and habitats Directive; the two directives can have shared areas. In Denmark around 935 km² are only Habitat Directive area and 5084 km² are exclusively Bird Directive area. Natura 2000 "Habitat Directive areas" in Denmark cover an area of 11.136 km² of which 71.5% are marine. The "Bird Directive Areas" represent a total area of 14.717km² of which around 82% are marine (www.skovognatur.dk) (Fig. 4.34).

Fig. 4.34. Marine Bird Directive Habitats in the Limfjord. (Source: DTU Aqua-GIS)

In the Limfjord area: 11 "marine habitats" with importance for birds were identified and listed (Table 4.12).

The Limfjord is home to a total of 32 EU-important bird species, with 13 bird species using it as a breeding area, 15 migratory bird species, 3 migratory birds breeding in the area and the international important migratory Bewick's swan being present in area Nr. F1 and F23. The highest diversity of breeding bird species are at Ulvedybet and Nibe Bredning (F1), Agger Tange (F23) and Harboøre Tange, Plet Enge and Gjeller Sø (F39) (Fig. 4.35).

Table 4.12. EU Bird Directive Habitats in Limfjorden. (Source : Danish Forest and Nature Agency)

Nr.	Name of Habitat (Location)	Areal ha
F1	Ulvedybet and Nibe Bredning	**18496**
F8	Coasts from Aggersund until Bygholm Vejle	1659
F14	Lovns Bredning	7513
F23	Agger Tange	**5453**
F24	Hjarbæk Fjord and Simested Fjord	4234
F25	Mågerodde and Karby Odde	497
F26	Dråby Vig	1678
F27	Glomstrup Vig, Agerø, Munkholm and Katholm Odde, Lindholm and Rotholme	6870
F28	Nissum Bredning	13562
F39	Harboøre Tange, Plet Enge and Gjeller Sø	7280
F40	Venø, Venø Sund	2926

A bird of special importance in the Limfjord is the great cormorant (*Phalacrocorax carbo*). For the past 10 years, there has been a constant 40 000 cormorant nests in Denmark, of which some 6000 were in Limfjord (Eskildsen, 2006).

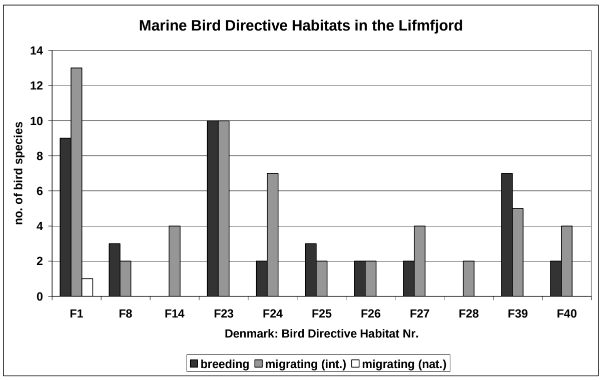

Fig. 4.35. Diversity of breeding bird species in Marine Bird Directive Habitats in the Limfjord. (Source : Danish Forest and Nature Agency)

Seal habitat

The harbour seal (*Phoca vitulinacan*) can be found along the coast in Northern Europe, and is the most common seal in Denmark (www2.dmu.dk). From an aerial survey in 1997, the Danish population of harbour seals was estimated to be 11 000 strong, of which 1400 inhabited Limfjord (NERI, unpublished data). Harbour seals fed almost exclusively on marine fish (Andersen *et al*. 2007). According to ICES the markedly decline of fish populations in the 1970s in the Limfjord and the increasing populations of seals and cormorants caused an increase in interactions between the fishery and cormorants and seals during the 1990s (Andersen *et al*. 2007).

Harbour seals and cormorants are often viewed as having a negative impact on commercial fish species; ICES showed that Atlantic herring was the only prey species on which harbour seal could have had a direct impact (Andersen *et al*. 2007). The harbour seal population in the Limfjord (1400 animals) consumed some 424 tons (based on daily consumption of 5kg per seal (Bonner 1982) of herring during 1997 compared with 2680 tons of herring landed by the commercial fishery (Andersen *et al*. 2007). The amount of herring consumed by seals is six times smaller than the fished amount and if it is assumed that there are sufficient small fish to sustain the stocks of fish at commercial size, the impact on the fishery in the Limfjord will be minor. However, if the seals and cormorants are limiting recruitment to commercial size, there will be competition (Andersen *et al*. 2007).

Bentihic organisms

Several species in the Limfjord have habitat-structuring features. Benthic vegetation such as eel grass and macroalgae assemblages create a 3-D habitat.

Eelgrass meadows represent a 3-D structure that functions as habitat, shelter, nursery and foraging areas for many species (comment Marianne Holmer, SDU). This service provided by eel grass in Limfjorden has been dramatically reduced due to the unfavourable environmental conditions mainly caused by eutrophication (see: *Cultural identity*).

Macroalgae enhance biodiversity by providing habitat and shelter for many species; furthermore they constitute a great part of the biodiversity in marine vegetation (NERI). The occurrence of macroalgae is mainly dependant on the availability of hard substratum and the light conditions in the water column. The surface area of firm substrata is likely to be particularly important in Danish estuaries where habitats for attached macroalgae are confined to stones, rock jetties, and chalky substrata scattered across the soft seabottom (Middelboe *et al*. 1998).

Aggregating macro-zoobenthos such as the Blue mussel beds represent hard substratum. Particularly in soft-bottom habitats, blue mussels constitute a dominant structural component (Frandsen and Dolmer 2002)

The habitats provided by eelgrass, macroalgae and mussel beds are nursery and foraging ground for many species (including commercially important marine species) and also can influence marine food webs by changing predator pressure. High complexity and heterogeneity of a substrate is believed to reduce predation pressure by increasing the number of spatial refuges (e.g. Moksness *et al.* 1998). In accordance with this hypothesis, Revelas (1982) found that the predation rate of shore crabs (*Carcinus maena*) on the blue mussels was 70% lower in an artificial *Spartina*/ *Fucus* marsh than on a mudflat In the Limfjord, the mussel fishery reduces substrate complexity by using dredges that remove large amounts of solid elements such as rocks and shell debris (Dolmer and Frandsen 2002).

Impact on settlement and recruitment was studied in experiments by Dolmer and Frandsen (2002). They confirmed several invertebrate larvae prefer complex substrata such as shell debris, gravel and macrophytes compared to sand and mud (Dolmer and Frandsen 2002). Removal of solid strucutures by dredging may therefore impoverish the seabed and decrease local recruitment (Dolmer and Frandsen 2002)

Hardbottom structures

In soft bottom habitats like the Limfjord solid elements, such as gravel and stone reefs are, beside the biogenic structures, of paramount importance to the benthic and pelagic community. Larval settlement and recruitment of many invertebrates are strongly influenced by substrate structure (Dolmer and Frandsen 2002). Compared with a smooth substrate such as mud or sand, the roughness of solid elements also increases turbulence of seston available to the benthic suspension feeders. Moreover, the solid elements serve as attachment sites and increase substrate heterogeneity and complexity, providing refuges for prey and predators (Dolmer and Frandsen 2002).

4.7.3. Resilience and resistance

Definition: The extent to which ecosystems can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or unexpectedly flipping to alternate states ("regime shift") (Hughes *et al*. 2005). Healthy ecosystems with high biodiversity can have greater resilience to natural or anthropogenic impacts (Hughes *et al*. 2005). However, high biodiversity alone does not necessarily lead to improved resilience. It is necessary to have a range of species that respond differently to various environmental perturbations to enhance resilience and/or resistance. For example, if all species within a functional group respond similarly to anthropogenic pressures, such as over fishing and pollution, increased biodiversity will not alleviate these pressures (Beaumont *et al.* 2007).

Ecosystem "health"

When discussing the resilience and resistance of the ecosystem Limfjord it is of utmost importance to include the historical development of the fjord.

The fjord is a highly dynamic system that has gone through large natural changes in its biological structure and functioning in the past. About 200 years ago the western Limfjord was a brackish ecosystem and after 1825; when the sea broke through the isthmus Aggertangen; the Limfjord changed into an estuarine system. This change in ecosystem structure is considered as a natural regime shift.

There is also evidence for another regime shift in the early 1970s (Collie *et al*. 2004), the period where the largest changes in Limfjords fish stocks took place (Hoffmann 2005). There are two different studies aiming to identify the drivers of the regime shift. In one survey the decline in landings have been correlated to the increased nutrient loading to the fjord (see Christiansen *et al*. 2006), whereas another study correlates patterns in fish abundance with the climate proxy, NAO (Northern Atlantic Oscillation) (Collie *et al*, 2004). Nevertheless both studies show that neither nutrient-load nor climate change alone can explain the observed regime shift.

Many different approaches to analyse the ecosystems present level of resilience and resistance exist. Two possible methods, based on the biodiversity concept mentioned earlier (Hughes *et al*. 2005) are first the number of species and second the number of functional groups that are present in the ecosystem. There is high certainty that a high diversity in species and functional groups increases the"response diversity" and "enables ecosystems to adjust in changing environments, altering biotic structures in ways that maintain processes and services. Thus the loss of biodiversity that is now taking place tends to reduce the resilience of ecosystems (MEA 2005).

As part of the research project REBECCA (Relationships between ecological and chemical status of surface waters; see Møhlenberg *et al.* 2003) the complexity of the food-web served as a proxy for the ecosystems "health".

In the study the ecosystem "health" of 4 eutrophic Danish Estuaries (including the Limfjord) was characterised by using Ecosystem Network Analysis. The output of a network analysis consists of a series indices, that quantify the systems health and integrity and that are used to evaluate the magnitude of stress imposed on an ecosystem (Møhlenberg *et al*. 2003).

The analysis shows that the ecosystem organisation of the Limfjord (Løgstør Basin) about 100 years ago was vastly different from the present organisation (Fig. 4.36). There has been an increase in a series of indices (total throughput, development capacity, ascendancy, *Finn cylcing index*) and most importantly the importance of detritivory increased, also reflected in a higher detritivory:herbivory ratio (D:H). ”A system dominated by detrivory represents a mature stage and a well-organized ecosystem with a web-like structure, while a grazer dominated sytem such as present Danish estuaries are characterized by low importance of detritivory and linear food chains (Odum 1969).

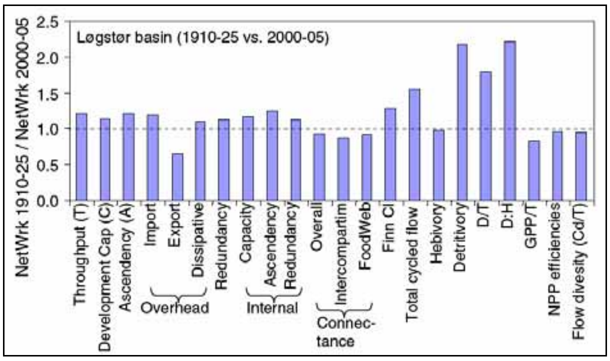

Fig. 4.36. Comparison of present and historic ratio of indices. (Source: Møhlenberg *et al.* 2003).

The study showed that food-web complexity of the Limfjord was reduced in comparison to about 100 years ago, resulting in a lower system resilience and resistance.

4.8. Economic valuation of EGS provided by the Limfjord

PROVISIONING SERVICES	Physical indicators	Economic valuation method
Food provision • Commercial fishing	- landings (tons) values of landings (kr.) biomass (tons)	a) Market price method
Raw material • Industrial fishing • Sand and gravel extraction	- landings (tons) values of landings (kr.) biomass (tons) - extracted material (m^3)	a) Market price method a) Market price method
REGULATION SERVICES		
Gas and climate regulation • CO_2 -sequestration	- area distribution of benthic vegetation (m^2)	b) Cost based method > marginal abatement costs for Europe
Water regulation • Goods transport • Passenger ferries	- through-put of goods (tons) - transported units (cars…)	a) Market price method a) Market price method
Disturbance prevention • Erosion control and sediment retention	- area distribution of benthic vegetation (m^2)	b) Cost based methods > damage or replacement cost
Bioremediation of waste • Denitrification and permanent burial of nitrogen • Permanent burial of phosphorous • Benthic micro-algae • Retention of N,P in living tissue	- removed N (tons) - removed P (tons) - area distribution (m^2); nutrient flux - N,P retained (tons) in biomass (tons) - N,P removed (tons) by fishery (tons)	b) Cost based method > Marginal abatement costs or shadow costs not known b) Cost based methods > Marginal abatement costs or shadow costs

CULTURAL SERVICE	Physical indicators	Economic valuation method
• Cultural heritage and identity • Early habitation • Maritime history • Traditional fishery	- landings (tons); values of landings (kr.); biomass (tons)	d) Stated preference method > Contingent valuation (CVM)
Cognitive benefits • Monitoring • Environmental education • Scientific research • Expected future-uses		Actual costs Actual costs (what to include?) Actual costs not known
Leisure and recreation • Sailing	- number of harbours and registered yachts; number of over-night guests.	c) Revealed preference methods > -Travel cost (TCM) > Market price
• Holiday cottages	- number of houses; rent	c) Revealed preference method > Hedonic pricing (HC)
• Camping	- number of camping sites - number of visitors - rent, fees	c) Revealed preference method > HC
Bathing	- number of beaches - number of visitors	c) Revealed preference methods > TCM and HC
Recreational fishery	- number of sold licenses	d) Stated preference method > CVM
• Other recreational activities		d) Stated preference method > CVM
Feel-good *Healthy environment:* • Biodiversity	- number of species - number of functional groups	d) Stated preference method > CVM
• Good water quality	- *secchi* depth	d) Stated preference method > CVM and HC
OPTION-USE VALUE		
Future unknown and speculative benefits • Biodiversity (genetic pool)		Stated preference method > CVM
SUPPORTING SERVICES	- not valuated	Would be “double-counting”

5. DISCUSSION

This paper identifies and characterizes the goods and services provided by the coastal zone (CZ) system Limfjord, and present an exploratory attempt to asses these goods and services based on limited primary data (telephone interviews and expert opinion interviews) and secondary data readily available. An already established framework of goods and services has been applied (see: MEA 2003) to enable comparison between studies.

The survey shows that the benefits derived from the Limfjord are vast, indicated by a comprehensive list of EGS. Nevertheless, it has to be kept in mind that the EGS approach is a reductionist approach that does not take into account the inter-dependency of the different ecosystem components. The Limfjord is well studied and a comprehensive amount of data is available. Readily available is environmental data, whereas socio-economic data is almost exclusively available for marketed goods. Data on ecosystem services characterized by being non-extractive and providing non-use values is hardly available/ existing or associated to a large effort in time and money. This indicates that the difficulties likely to arise are the valuation of EGS and especially services, when working on a short time scale. Limited knowledge should not, however, be used as an excuse and thus the viability and potential of different methods such as benefit transfer of values should be analysed and exploited.

During the survey it also become quite clear that the Limfjord, is a complex and dynamic CZ system is, which makes is difficult to clearly distinguish between natural or anthropogenic caused changes in the ecosystems "health". Since environmental managers and in consequence policy makers need to get a true idea of the impact of development or human activity it has to be distinguished between marginal changes caused naturally or due to anthropogenic activity. Historical development plays a fundamental role in assessing EGS.

The results of this study highlight that many of the identified EGS have already been notably degraded/ reduced due to extensive exploitation of the resources and/ or due to alteration/ transformation of the ecosystem's functions. But also that that other services such as the recreation sector show large future potential.

In summary, the established framework for EGS should be promoted among scientists to enable discussion and comparison between sites and to make benefit transfer of values possible.

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Danish Directorate of Fisheries: www.fd.dk
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World Tourism Organization: www.unwto.org

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Appendix I

Project N° : 036992

Science Policy Interface for Coastal Systems Assessment

Assessment of valuable Ecosystem Services provided by

The Coastal Zone System Limfjord, Denmark

3-months study (August – October)

Consultation document

The purpose of this survey is the assessment of valuable Ecosystem Services provided by the Coastal Zone (CZ) System Limfjord. The **identification and listing of ecosystem services** is part of the SPICOSA System Design and will provide the basis for ecosystem services valuations. My understanding of Ecosystem services is the direct and indirect benefits people obtain from the natural environment including goods (such as food) and multiple services (such as regulating, cultural and supporting services). It is important that the information about ecosystem services and their values is made available and becomes a part of the information-set used in policy decisions (Bingham, Bishop *et al*. 1995), because in decisions about resource use these services and their values are often overlooked (Vaze, Dunn *et al*. 2006).

The Limfjord is a complex ecosystem being exposed to multiple human activities and a valuable list of ecosystem services is dependant on as much as possible expertise information.

Guiding information for the survey

1. The example sheet helps you to get familiar with the different types of "Ecosystem Goods and Services" (EGS) beforehand.

2. "List of EGS" to be filled out during the telephone appointment we have agreed on by e-mail.
   - There is open-space for additional EGS and information. This space is for services you would like to mention but that are not listed.
   - "Contact persons" please identify researchers/ managers that could help completing the EGS list in the section.
3. Following to the telephone conversation I will send the completed document to you and I kindly ask you to endorse it and apply corrections where needed.
4. Do not hesitate to contact me if you have questions/suggestions etc.

Thank you for your time!

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Ecosystem goods and services (MEA 2003; Beaumont, Austen *et al*. 2007)

Category	Definition	Examples of goods and services provided
Provisioning services	Products obtained from the ecosystem	1. **Food provision** (e.g. seafood products...) 2. **Raw materials** (e.g. renewable biotic resources such as wood, fibre...) 3. **Genetic, medical and ornamental resources** (e.g drugs, pharmaceuticals, food additives; resources for handicraft…) 4. **Water supply** (e.g. consumptive use of water by households, agriculture, industry…)
Regulation services	Biophysical processes controlling natural processes	5. **Gas (and climate regulation** (e.g. maintenance of good, air quality, source/sink for CO_2, O_2 /CO_2 -balance, maintenance of a favourable climate…) 6. **Disturbance prevention** (e.g. storm /flood protection due to present structures in the ecosystem…) 7. **Water regulation** (e.g. maintenance of natural irrigation and drainage, medium for transportation such as shipping..) 8. **Bioremediation of waste** (e.g. storage and recycling of organic/ inorganic human waste…)
Cultural services	Non-material benefits people obtain from ecosystems	9. **Cultural heritage and identity** (e.g. culture such as traditional fisheries,…) 10. **Leisure and recreation** (e.g. tourism, recreational activities …) 11. **Cognitive benefits** (e.g. nature study, environmental education and scientific research, monitoring area/ stations…) 12. **Feel-good** Non-use benefits (e.g. existence value of biodiversity…)
Option-use value		13. **Future unknown and speculative benefits**
Supporting services	Necessary for the production of all other ecosystem services, but do not yield direct benefits to humans	14. **Primary production** 15. **Biologically mediated habitat** (e.g. living space, breeding and nursery areas,…) 16. **Nutrient cycling** 17. **Soil formation and retention** 18.**Resilience and Resistance**

Appendix II

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